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Houghton, J. T., B. A. Callander and S. K. Varney (1992) Climate Change 1992. The Supplementary Report to the IPCC Scientific Assessment. Report Prepared for IPCC by Working Group 1. Intergovernmental Panel on Climate Change. University Press, Cambridge.

IPCC (1992) 1992 IPCC Supplement, Full Scientific Report. International Panel on Climate Change.

Lovins, A. B., L. H. Lovins, F. Krause and W. Bach (1981) Least-cost Energy, Solving the CO2 problem. Brick House Publ., Andover, USA.

Matsuoka, Y., T. Morita, and M. Kainuma (1992) Scenarios on Global Warming and Their Model Analysis. Proceedings of JSCE, No.449/IV-17, 1-16 (written in Japanese, to be published in English).

Matsuoka, Y. and T. Morita (1993a) Some Analysis on Global Environment and Population Changes. Environmental System Studies, No.21, 72-80 (written in Japanese, to be published in English).

Matsuoka, Y. and T. Morita (1993b) An Analysis of the Consistency between Population and Economic Growth Assumptions used for Forecasting Greenhouse Gas Emissions. Prepared for Authors Meeting of IPCC Working Group III Writing Team 10, 14-15 January 1994, Tsukuba, Japan.

Mesarovic, M. and E. Pestel (1974) Mankind at the Turning Point: The Second Report to the Club of Rome. Dutton, New York.

Morita, T.(1992) Survey of Global Model Scenario Input Assumptions. 39 pages, mimeo.

Morita, T. and Y. Matsuoka (1993) Preliminary Results and Conclusions on Emission Scenarios and Their Assumptions. Prepared for Lead Authors Meeting of IPCC WGIII Writing Team 10, 8-9 December 1993, Amsterdam, 15 pages.

Morita, T., Y. Matsuoka, M. Kainuma, H. Harasawa and K. Kai (1993) AIM - Asian Pacific Integrated Model for Evaluating Policy Options to Reduce

GHG Emissions and Global Warming Impacts. Proceedings of the Workshop on Global Warming Issues in Asia, Bangkok, 8-10 September, 26 pages (to be published as a book from AIT).

Nordhaus, W. D. and G. W. Yohe (1983) Future Paths of Energy and Carbon Dioxide Emissions, (in) Changing Climate: Report of the Carbon Dioxide Assessment Committee, National Academy Press, Washington, D.C. 87-153.

RSWG (1990) Emission Scenarios. Response Strategies Working Group of the Intergovernmental Panel on Climate Change. 58 pages.

USBC (1987) World Population Profile: 1987. United States Bureau of Census, U. S. Department of Commerce, Washington D. C.

United Nations (1992) Long-range World Population Projections: Two Centuries of Population Growth, 1950-2150. United Nations Publication, Sales No.E.92, XIII.3.

World Bank (1990) World Development Report 1991. Oxford University Press, 290 pages.

APPENDIX 1

GHG EMISSION MODELS
AND
RELATED MODELS

(Model Information)

Model Name	Model Developer
Model Type	Forecast Period
Literature	
Assumptions	
Latest Information	

Listed alphabetically by model developer.

IMAGE 2 — Alcamo et al.
Multi-disciplinary, integrated model — 1990-2100

Alcamo, J., G.J.J. Kreileman, M. Krol and G. Zuiema (1993) Modelling the Global Society-Biosphere-Climate System: Part 1: Model Description and Testing. *Papers of International Workshop on Integrative Assessment of Mitigation, Impacts and Adaptation to Climate Change*, 13-15 October, 1993, Laxenburg, Austria.

Alcamo, J., G.J.J. Kreileman, M. Krol and G. Zuiema (1993) Modelling the Global Society-Biosphere-Climate System, Part 2: Computed Scenarios. *Water, Air, Soil, Pollution* (Submitted).

Computes greenhouse gas emissions as a function of energy consumption and industrial production; simulates changes in global land cover based on climatic and economic factors; and computes the buildup of greenhouse gases and resulting zonal average temperature and precipitation patterns.

ENERGY SCENARIOS MODEL — Anderson and Bird
Top-down. Models energy sector, technology selection, technological development. Calculates the effect on economic growth having first estimated the costs. — 1990-2050

Includes a relationship between investment and cost reduction in alternative supply technologies.

Latest information on this model

Anderson, D. and C.D. Bird (1992) *Carbon Accumulations and Technical Progress - A Simulation Study of Costs.* Oxford Bulletin of Economics and Statistics, Vol. 54, No. 1, Feb.

"Business As Usual" Scenario

Population: Exogenous; 1990: 5.284 billion; Growth rate to 2025: 1.3%/annum; 2050: 10 billion, 0.75%/annum.

Economic growth: Endogenous; 2000: $25,000 billion; Growth rate 2000-2020: 3.2%/annum; 2050: $105,000 billion; Growth rate 2020-2050: 2.7%/annum. 1990 dollars.

Technology: AEEI: 1%/annum; Assumes back-stop technologies, the main one of which is solar energy and other forms of renewable energy. Their costs decline with investment and technical progress.

Energy price: Exogenous; Oil: $25/bbl. (ex-refinery) rising to $40/bbl.

Energy reserves: Supply elasticities are related to future price. Fossil fuel reserves are needed over the period, but there is a gradual shift to "synfuels" over the next half century.

Other: The marginal costs of the backstop technologies are determined in the liquid fuel market by the costs of hydrogen and the fuel cell electric vehicle. This amounts to less than $20/bbl.

Emissions: Fossil fuel CO2: 1990: 6 billion tones C; 2050: 20 billion tonnes C.

Special characteristics: In the Renewable energy scenario, as renewables are substituted for fossil fuels, CO2 emissions rise to 8 billion tonnes of carbon in 2020 and decline to 6 billion in 2050, and prospectively 0 in 2100.

METHANE ECONOMY — Ausubel, Grübler, Nakićenović
Market penetration model — 1850-2100

Latest information on this model

Ausubel, J.H., A. Grübler and N. Nakićenović (1988) *Carbon Dioxide Emissions in a Methane Economy* . IIASA Reprint RR-88-7, December, Laxenburg, Austria, Reprinted from Climate Change 12 (1988) pp. 245-263.

"Business As Usual" Scenario

Population: 1987: 5 billion; 2100: 10.4 billion.

Energy consumption: Primary energy use and market shares for efficiency and long-wave scenarios (btce, rounded figures).

			Efficiency scenario			Long-wave scenario		
Year	1986		2030		2100	2030		2100
Wood	< 1	(1%)	< 1		< 1	< 1		< 1
Coal	2	(21%)	< 1		< 1	1	(3%)	< 1
Oil	4	(41%)	2	(11%)	< 1	4	(11%)	< 1
Gas	3	(34%)	12	(69%)	3 (14%)	23	(69%)	16 (14%)
Nuclear	< 1	(3%)	3	(16%)	13 (63%)	5	(16%)	77 (63%)
Solfus	0		< 1		5 (23%)	< 1		27 (23%)
Total energy consumption	10		17		21	33		120

Energy reserves: Global conventional and inconventional gas are accepted to be about 4,600 billion tonnes C.

Deforestation/Afforestation: Not included.

GLOBAL 2000 MODEL — Barney
Unified sectorial model — 1975 - 2000

Barney, G.O. (1980) *The Global 2000 Report to the President.* U.S. Government Printing Office, Washington, D.C.

Population: 2000: 5.9-6.8 billion; GNP Growth rate: 3.6% (medium); GNP: 2000: 14.7 trillion 1975 US dollars (medium); Resources: Oil: 645.85 billion bbl., Gas: 2,519,659 billion cu ft, Coal: 786 billion tonnes.

FOSSIL 2 - AES
Recursive generalized equilibrium
(US energy markets)

Belanger and Neill
1990 - 2030

Gaskins, D.W., Jnr. and J.P. Weyant (1993) Tentative Conclusions from Energy Modelling Forum Study Number 12 on Controlling Greenhouse Gas Emissions. in Y. Kaya et al. (Eds.) *Costs, Impacts, and Benefits of CO2 Mitigation*, Proceedings of a Workshop held on 28-30 September 1992 at IIASA, Laxenburg, Austria, pp. 235-246.

GDP, Prices, Energy supply, price and mix, Energy supply and demand technologies, CO2 emissions, Carbon offset. Equilibrium in energy sector's markets: primary, secondary, electric, etc. No markets for capital, labor, or other nonenergy goods. Reference GDP and/or energy service demand exogenously-given. Price and/or GDP effects on demand through aggregate 'feedback equations'.

GLOBUS
Nation-based political-economic
discrete-time-step model

Bremer et al.
1970 - 2010

Bremer, S.A. (Ed.) *The GLOBUS Model: Computer Simulation of Worldwide Political and Economic Developments.* Frankfurt am Main: Campus Verlag or Boulder, Westview Press.

Population: 2025: 7.2-9.1 billion; GNP: 2025: 15 trillion US dollars (estimate).

WORLD BANK POPULATION

Bulatao et al.

Bulatao, R.A., E. Bos, P.W. Stephens and M.T. Vu (1990) *Population Projections, 1989-90 edition. Short and Long-term estimates.* The World Bank, John Hopkins University Press.

World Population: 2100: 11.3 billion.

CHANDLER
Edmonds-Reilly

Chandler
1975 - 2025

Chandler, W. (1985) *Energy Productivity: Key to Environmental Protection and Economic Progress* . Worldwatch Paper 63, Worldwatch Institute, Washington, D.C.

BEEAM (Brookhaven Energy Economic Assessment Model)
Linear program model

Cherniavsky

Cherniavsky, E. (1974) *Brookhaven Energy System Optimisation Model.* Topical Report BNL 50873, Brookhaven National Laboratory, N.Y.

ESCAPE
Bottom-up, partial equilibrium.
Models energy sector, technology selection, technological development, land-use/agric., and linked to climate change/impact model.

Climatic Research Unit
- Netherlands
1990-2100

Latest information on this model

Rotmans, J., M. Hulme and T.E. Downey (1994) Climate change implications for Europe: an application of the ESCAPE model. *Global Environmental Change*, (in press).

Hulme, M. and S. Raper (1993) An Integrated Framework to Address Climate Change (ESCAPE) and Further Developments of the Global and Regional Climate Modules (MAGICC). Climatic Research Unit, School of Environmental Sciences, University of East Anglia, Norwich, England. *Papers of International Workshop on Integrative Assessment of Mitigation, Impacts and Adaptation to Climate Change*, 13-15 October, 1993, Laxenburg, Austria.

"Business As Usual" Scenario

Population: Exogenous; regional growth rates only.

Economic growth: Exogenous; regional growth rates only.

Energy prices: Exogenous.

Energy reserves: Supply elasticities not related to future price.

Deforestation/Afforestation: Image 1.5 land use model; deforestation is driven by demand for food products; land conversion is modelled accordingly.

Emissions: Fossil fuel CO2: 1990: 5.85 billion tonnes C; 2100: 20.21 billion tonnes C
Anthropogenic CO2: 1990: 7.87 billion tonnes C; 2100: 21.09 billion tonnes C
Anthropogenic CH4: 1990: 414.74 million tonnes CH4; 2100: 998.46 billion tonnes CH4
Anthropogenic N2O: 1990: 9.21 million tonnes N2O; 2100: 10.87 million tonnes N2O
Anthropogenic CFC11 equiv.: 1990: 0.876 million tonnes; 2100: 3.015 million tonnes

Special characteristics: Uses IMAGE 1.5 to calculate emissions from land-use changes.

MAGICC
Integrated individual components

Climate Research Unit
1990-2100

Hulme, M. and S. Raper (1993) An Integrated Framework to Address Climate Change (ESCAPE) and Further Developments of the Global and Regional Climate Modules (MAGICC) Climatic Research Unit, School of Environmental Sciences, University of East Anglia, Norwich, England. *Papers of International Workshop on Integrative Assessment of Mitigation, Impacts and Adaptation to Climate Change*, 13-15 October, 1993, Laxenburg, Austria.

COLOMBO-BERNADINI — Colombo and Bernadini
1975 - 2030

Colombo, U. and O. Bernadini (1979) *A Low Energy Growth 2030 Scenario and the Perspectives for Western Europe.* Report to the Commission of the European Communities, Brussels.

PNL/OTA
ERB Version 4.01 — Edmonds, Barnes, Ton
1990-2095

Edmonds, J., D.W. Barns and M. Ton (1993) The Regional Costs and Benefits of Participation in Alternative Hypothetical Fossil Fuel Carbon Emissions Reduction Protocols. in Y. Kaya et al. (Eds.) *Costs, Impacts, and Benefits of CO2 Mitigation*, Proceedings of a Workshop held on 28-30 September 1992 at IIASA, Laxenburg, Austria, pp. 291-314.

Population: 2095: 10.4 billion; Labor productivity growth rates: 2095: 0.93-2.85; Energy end-use energy intensity improvement rate: 1%.

EDMONDS & REILLY
Partial Equilibrium — Edmonds and Reilly
1975 - 2050

Edmonds, J.A. and J.M. Reilly (1983) Global Energy and CO2 to 2050. *The Energy Journal*, Vol. 4, No. 3, pp. 21-47.

Edmonds, J.A., J.M. Reilly, J.R. Trabalka and D.E. Reichle (1984) *An Analysis of Possible Future Atmospheric Retention of Fossil Fuel CO2.* (DOE/OR/21400-1) U.S. Department of Energy, Washington D.C. Available from NTIS, Springrield, Va.

Edmonds, J.A. and J.M. Reilly (1985) *Global Energy: Assessing the Future.* Oxford University Press, N.Y.

Edmonds, J.A., J.M. Reilly, R. Gardner, and A. Brenkert (1985) *Uncertainty in Carbon Emissions, 1975 - 2075 (Contractor Report).* Institute for Energy Analysis, Oak Ridge, Tenn. Available from NTIS, Springfield, Va.

Edmonds, J.A. and J.M. Reilly (1986) *The Long-Term Global Energy-CO2 Model: PC version A84PC.* Carbon Dioxide Information Center, Oak Ridge, Tenn.

Barns, D.W., J.A. Edmonds, and J.M. Reilly (1992) *Use of the Edmonds-Reilly Model to Model Energy-Related Greenhouse Gas Emissions.* Economics Department Working Papers No. 113, OECD, Paris.

Population: 2075: 8.45 billion; GNP growth rate: (1975-2050) 1.8-2.6 %; GNP: 2050: $24.8-42.6 trillion (1975 US dollars).
Global fuel markets, GNP, Population, Energy price and supply, Technological changes. Equilibrium in energy sector's markets: primary, secondary, electric, etc. No markets for capital, labor, or other nonenergy goods. Reference GDP and/or energy service demand exogenously-given. Price and/or GDP effects on demand through aggregate 'feedback equations'.

SECOND GENERATION MODEL — Edmonds et al.
General Equilibrium

Edmonds, J.A., H.M. Pitcher, D. Bams, R. Baron and M.A. Wise (1991) *Modelling Future Greenhouse Gas Emissions: The Second Generation Model Description.* Presented at the UNU Conference on "Global Change and Modelling." Tokyo, Japan.

Fisher-Vanden, K. et al. (1993) The Second Generation Model of Energy Use, the Economy, and Greenhouse Gas Emissions. Presented to the 6th Annual Federal Forecasters Conference, Crystal City, Va., September, 1993, *Papers of International Workshop on Integrative Assessment of Mitigation, Impacts and Adaptation to Climate Change*, 13-15 October, 1993, IIASA, Laxenburg, Austria.

GCAM — Edmonds et al.
Integration of various models

Edmonds, J.A., H.M. Pitcher, N.J. Rosenberg and T.M.L. Wigley (1993) Design for the Global Change Assessment Model - GCAM. *Papers of International Workshop on Integrative Assessment of Mitigation, Impacts and Adaptation to Climate Change*, 13-15 October, 1993, Laxenburg, Austria.

Currently being developed to increase understanding in the area of integrated global change analysis.

CSERGE — Fankhauser
Stochastic greenhouse damage model — 1991-2030

Fankhauser, S. (1993) The Social Costs of Greenhouse Gas Emissions: An Expected Value Approach. Centre for Social and Economic Research on the Global Environment. University College London and University of East Anglia. *Papers of International Workshop on Integrative Assessment of Mitigation, Impacts and Adaptation to Climate Change*, 13-15 October, 1993, Laxenburg, Austria.

Assesses the marginal social costs of greenhouse gas emissions.

IIASA
IBSNAT and BLS
General equilibrium model

Fischer et al.
1980-2060

Fischer, G., K. Frohberg, M. L. Parry and C. Rosenweig (1993) Climate Change and World Food Supply, Demand and Trade. in Y. Kaya et al. (Eds.) *Costs, Impacts, and Benefits of CO2 Mitigation*, Proceedings of a Workshop held on 28-30 September 1992 at IIASA, Laxenburg, Austria, pp. 133-151.

Using different scenarios of climate change, the effects on crop yields and food trade were estimated. Assumptions used relate to CO2 doubling, impacts on plant growth and yield, farm level adaptation, and policy changes (e.g. population growth, economic growth).

BACK-OF-THE ENVELOPE
Input-Output

Fritsch et al.
1975 - 2020

Fritsch, C. et al. (1980) The use of input-output techniques in an energy-oriented model. in Bruckmann (Ed.) *Input-output approaches in global modeling*, Pergamon Press. N.Y.

Population: 2020:7.8-15.1 billion; GDP Growth rate: 2-4%; World energy consumption: 18.5-44.3 TW; Energy efficiency: 0.93 or 1.43 W/$

GOLDEMBERG
Bottom-up global study with disaggregation
of global energy use and technologies.

Goldemberg et al.

Goldemberg, J., T.B. Johansson, A.K. Reddy, R.H. Williams (1987) *Energy for a Sustainable World.* Wiley-Eastern, New Delhi.

GOULDER MODEL
Bottom-up,
dynamic general equilibrium
of the U.S. with foreign trade.
Models energy sector, technology selection
and international trade.

Goulder
1990 - 2100

Latest Information on this model

Goulder, L. H. (1993) *Effects of Carbon Taxes in an Economy with Prior Tax Distortions: An Intertemporal General Equilibrium Analysis.* Working Paper, Stanford University, January.

Goulder, L. H. Energy Taxes: Traditional Efficiency Effects and Environmental Considerations. in J.M. Poterba, (Ed.) *Tax Policy and the Economy 8*, MIT Press, Cambridge, Mass. (forthcoming).

Goulder, L. H. The Goulder Model: Structure and Simulation Results. in D. Gaskins and J. Weyant (Eds.) *Reducing Carbon Emissions from the Energy Sector: Cost and Policy Options*, Stanford University Press. Stanford, Cal. (forthcoming).

"Business As Usual" Scenario

Population: Exogenous; 250 million at 1990, growing at 0.5%/annum. (Labor force participation: endogenous).

Economic growth: Endogenous; Indices: GNP and Consumption. GNP: 1990: $5,604.4 billion; 2060: $21,843.2 billion (1990 dollars) Consumption: 1990: $2,869.7 billion; 2060: $10,877.3 billion (1990 dollars).

Technology: Harrod-neutral (or labor-embodied) technological progress at 1.5%/annum. AEEI is 0.

Energy prices: Except for oil, domestic prices are endogenous. The world price for oil is exogenous, set in real terms and grows from $24/bbl. in 1990 by $6.50/bbl./decade.

Energy reserves: Domestic crude and natural gas reserves are 450 billion bbl. in 1990 and reduce annually by the level of production.

Deforestation/Afforestation: Not modelled.

Carbon Emissions: 1990: 1.551 billion tonnes C, 2060: 6.348 billion tonnes C.

Special Characteristics: Incorporates the exhaustible nature of oil and gas production in a forward-looking optimizing framework, as well as the transition to a backstop technology. This is complemented by the endogenous treatment of the market penetration of carbon-based synthetic fuels (shale oil). Indicates that models that neglect other pre-existing taxes may significantly understate the costs of carbon taxes or other environmental tax initiatives.

HÄFELE MODEL — Häfele
IIASA - World energy model — 1975 - 2030

Häfele, W. (1981) *Energy in a Finite World: A Global Systems Analysis.* Ballinger, Cambridge, Mass.

Population: 2030: 8 billion; GDP growth rate: (1975-2000) 3.1-4.2 %; GDP: 2000: 13.4-17, 2030: 1975 $U.S. 22.4-40 trillion; Resources: Oil: 2100 billion bbl., Gas: 291 trillion m3, Coal: 605 billion tonnes C equiv.

IEA WORLD ENERGY MODEL — International Energy Agency
Econometric. Models energy sector. — Economic Analysis Division

Explicit technological variables in transportation and power generation sectors.	1965 - 2005 1990-2010

Gaskins, D.W., Jnr. and J.P. Weyant (1993) Tentative Conclusions from Energy Modelling Forum Study Number 12 on Controlling Greenhouse Gas Emissions. in Y. Kaya et al. (Eds.) *Costs, Impacts, and Benefits of CO2 Mitigation*, Proceedings of a Workshop held on 28-30 September 1992 at IIASA, Laxenburg, Austria, pp. 235-246.

Vouyoukas, L. (1992) *Carbon taxes and CO2 emission targets: results from the IEA model.* OECD Economics Department Working Paper No. 114.

Historical energy demand, Economic growth, Population, Relative prices, Energy supply mix. Equilibrium in energy sector's markets: primary, secondary, electric, etc. Five fuel sources with many product breakdowns. Much energy detail for OECD regions. No markets for capital, labor, or other non-energy goods. Reference GDP and/or energy service demand exogenously-given. Price and/or GDP effects on demand through aggregate 'feedback equations'.

Latest information on this model

Latest reference: April 1993; next release: April 1994.

"Business As Usual" Scenario

Population: Exogenous; Growth rate 1990-2010: 1.5%.

Economic growth: Exogenous; Growth rate 1990-2010: 2.7%.

Technology: Assumptions depend on sector; No backstop technologies assumed; no policy initiatives beyond those already legislated.

Energy prices: Primary fuel prices are exogenous; end-use prices are endogenous. The price of crude oil rises to $30/bbl.

Energy reserves: Supply elasticities are related to future prices.

Other: No new policy initiatives

Emissions: Fossil fuel CO2: 1990: 5.703 billion tonnes C; 2010: 8.376 billion tonnes C.

Special characteristics: The incorporation of historical behaviour and the weak link between primary and enduse energy prices shows that the energy system area in the medium term is very inflexible.

EMISSION EXPERTS Atmospheric stabilization framework	IPCC 1985 - 2100

RSWG (Response Strategies Working Group) of the Intergovernmental Panel on Climate Change (1990) *Emissions Scenarios. Appendix of the Expert group on Emission Scenarios.* Prepared by April.

Population: 2100: 10.4 billion; GNP Growth: Regional estimates based on World Bank (1987) - declining to 1.3-2.6% between 2025-2100; Oil price: 2000: 1988 US$ 22-28/bbl.; Energy efficiency improvements: 1.2 - 1.9%/year.

IPCC Supplementary Report	IPCC
ASF	1990-2100

Houghton, J.T., B.A. Callander and S.K. Varney (1992) *Climate Change 1992.* The Supplementary Report to the IPCC Scientific Assessment. Report prepared for IPCC by Working Group 1. Intergovernmental Panel on Climate Change. University Press, Cambridge, Mass.

Pepper, W.J., J.A. Leggett, R.J. Swart, J. Wasson, J. Edmonds and I. Mintzer (1992) *Emission Scenarios for the IPCC - an Update: Background Documentation on Assumptions, Methodology and Results.* U.S. Environmental Protection Agency, Washington, D.C.

IS92a - Population: 2100: 11.3 billion; Economic growth: 1990-2100: 2.3%;Energy: Oil: 12,000 EJ, Natural Gas: 13,000 EJ, Solar: $0.075/kWh, Biofuels: 191 EJ @ $70/bbl.

IS92b - Population: as for IS92a; Economic growth: as for IS92a; Energy: as for IS92a.

IS92c - Population: 2100: 6.4 billion; Economic growth: 1990-2100: 1.2%; Energy: Oil: 8,000 EJ, Natural Gas: 7,300 EJ, Nuclear: costs decline by 4%/yr.

IS92d - Population: 2100: 6.4 billion; Economic growth: 1990-2100: 2.0%; Energy: Oil and gas: same as IS92c, Solar: $0.065/kWh, Biofuels: 272 EJ @ $50/bbl.

IS92e - Population: 2100: 11.3 billion; Economic growth: 1990-2100: 3.0%;Energy: Oil: 18,400EJ, Gas: same as IS92a; Nuclear: none by 2075.

IS92f - Population: 2100: 17.6 billion; Economic growth: 1990-2100: 2.3%; Energy: Oil and Gas: same as IS92e; Solar: $0.083/kWh, Nuclear: costs up to $0.09/kWh.

JASON	Jason
	1975 - 2075

Jason (1979) *A Long-Term Impact of Atmospheric Carbon Dioxide on Climate* (Technical Report JSR-78-07). SRI International, Arlington, Va.

Renewables Intensive Global Energy	Johansson, Kelly, Reddy, Williams
Scenario (RIGES)	1985-2050
Integration of regional energy	

supply scenarios, with
emphasis on renewable supplies.

Latest information on this model

Burnham, L., T.B. Johansson, H. Kelly, A.K.N. Reddy, R.H. Williams (1993) *Renewable Energy: Sources for Fuels and Electricity.* Island Press, Wash., U.S.A.

High Economic Growth, High Energy Efficiency Scenario

This is not a "business as usual" scenario. It uses the 1990 IPCC Response Strategies Working Group's high economic growth, high energy efficiency scenario demand projections for electricity and for gaseous, liquid and solid fuels. It matches regional demand projections with constructed supply mixes that emphasize renewable alternative energy supplies and take into account regional endowments of both conventional and renewable energy sources, as well as relative prices of alternative energy supplies.

Population: 1985: 4.874 billion, 2050: 9.521 billion.

Economic growth: Per capita GDP: 1985: $ 3,232; 2050: $ 13,636 (1989 US dollars).

Technology: Assumes high rates of technological innovation and substitution of renewable energy technologies. These are in turn assumed to be dependent on a high rate of economic growth.

Energy Prices: Assumes world oil price does not move above $25/bbl.

Global Energy Use: Total Primary Energy Inputs EJ per year

	1985	2025	2050
Coal	90.0	88.8	59.0
Oil	127.2	76.5	64.3
Natural Gas	64.9	93.2	107.9
Hydro	20.5	30.3	31.8
Nuclear	15.3	14.8	12.2
Geothermal	0.1	1.6	1.4
Commercial Biomass	4.8	145.6	206.4
Non-Commercial Biomass	50.0		
Intermittent Renewables		37.4	63.7
Solar H2		9.8	14.4
TOTAL	372.8	498.0	561.4

Global fuel supply scenario (commercial fuels only): EJ per year

	1985	2025	2050
Fossil fuels (coal, oil, natural gas)	282.5	258.5	231.2
Solid biomass and other solids	5.0	33.1	47.8
Liquid MeOH and EthOH	0.0	45.4	62.5
Biogases plus H2 from biogas and intermittent renewables	0.0	35.4	53.8
TOTAL	287.6	372.4	395.3

Deforestation/Afforestation: Promotes large-scale plantation establishment as part of an increasing use of renewable biomass energy sources.

Emissions: Commercial fuel CO2 (Includes: fossil fuels, biomass and other gaseous, liquid and solid fuels): Total: 1985: 5,633 MtC, 2025: 4,965 MtC, 2050: 4,191 MtC. Per Capita: 1985: 1.158tC, 2025: 0.607tC, 2050: 0.440tC.

Special characteristics: A high economic growth rate was chosen because the authors consider that high rates of technological innovation could not be achieved without it. Also, a high energy efficiency scenario was chosen because it was felt that an emphasis on renewables makes the most sense for an economy where cost-effective opportunities for making more efficient use of energy are exploited first. It assumes that policies are adopted to speed up the rate of development of renewables.

DGEM (Dynamic General Equilibrium Model) — Jorgensen and Wilcoxen
Intertemporal general equilibrium of US with aggregate ROW sector — 1947 - 2050

Jorgenson, D. and P. Wilcoxen (1990) Environmental Regulation and US Economic Growth. *RAND Journal of Economics*, Vol. 21, pp. 314-340.

Gaskins, D.W., Jnr. and J.P. Weyant (1993) Tentative Conclusions from Energy Modelling Forum Study Number 12 on Controlling Greenhouse Gas Emissions. in Y. Kaya et al. (Eds.) *Costs, Impacts, and Benefits of CO2 Mitigation*, Proceedings of a Workshop held on 28-30 September 1992 at IIASA, Laxenburg, Austria, pp. 235-246.

Industry and household cost and expenditures, US government and ROW sectors, Economic growth, Energy supply and costs (energy resources are inexhaustible), Productivity changes, Carbon emissions. Market equilibria for all goods: capital, labor, materials, other goods. Consumers choose savings/investment levels. GDP, energy intensity changes determined by interactions throughout the economy. Less detail in energy sector.

T-GAS (Trace Gas Accounting System) — Kaufmann
Regression model of country and end-use sector-specific fuel intensity — 1971 -2010

Gaskins, D.W., Jnr. and J.P. Weyant (1993) Tentative Conclusions from Energy Modelling Forum Study Number 12 on Controlling Greenhouse Gas Emissions. in Y. Kaya et al. (Eds.) *Costs, Impacts, and Benefits of CO2 Mitigation*, Proceedings of a Workshop held on 28-30 September 1992 at IIASA, Laxenburg, Austria, pp. 235-246.

14 country aggregation, Fuel use per economic output, GDP-related values, Fuel supply mix, Historical supply technological change patterns. Exogenous inputs of prices, GDP, population, etc. Energy intensity by sector determined from regression equation and given inputs. Some user control over parameters in functions.

KEELING-BACASTOW — Keeling and Bacastow
1975 - 2100

Keeling, C.D.C. and R.B. Bacastow (1977) Impact of Industrial Gases on Climate. in *Energy and Climate*, National Academy of Sciences, Washington, D.C.

Bacastow, R.B. and C.D. Keeling (1981) Hemispheric Airborne Fractions Difference and the Hemisperic Exchange Time. in B. Bolin (Ed.) *Carbon Cycle Modelling, SCOPE 16*, John Wiley & Sons, N.Y., pp. 241-246.

GREENPEACE — Lazarus et al.
ASF — 1990-2100

Lazarus, M., L. Greber, J.Hall, C. Bartels, S. Bernow, E. Hansen, P. Raskin and D. Von Hippel (1993) *Towards a Fossil Free Energy Future - The Next Energy Transition. A Technical Analysis for Greenpeace International.* Stockholm Environment Institute - Boston Center, Boston, Mass., U.S.A.

Waide, P. (1993) *Technical Annex for Greenpeace International. Towards a Fossil Free Energy Future - The Next Energy Transition.* Economic Issues, May.

Population: 2100: 11+ billion; GDP: 2100: US$212 trillion; GDP/capita: 2100: US$ 18,788 (regional income ratio 2:1); Delivered Energy: 2100: 448 EJ, Primary Energy: 2100: 987 EJ (Fossil Fuel and Nuclear phase-out); Energy/GDP: 2100: 5KJ/$.

U.N. WORLD ECONOMIC MODEL — Leontief, Carter et al.
Macroeconomic Leontief input-output system — 1970 - 2000

Leontief, W., A. Carter et al. (1977) *The Future of the World Economy: A United Nations Study.* Oxford University Press, N.Y.

Petri, P.A. (1977) An Introduction to the Structure and Application of the United Nations World Model. *Applied Mathematical Modelling*, Vol. 1, No. 5, pp. 261-268.

Menshkov, S.M. (1980) Using the Global Input-output Model for Long-term Projections. in *Input-output Approaches in Global Modeling*, Pergamon Press, N.Y., pp. 13-30.

Population growth: 1970-2075: Developed countries: 0.7%, Developing countries: 2.3%; after 2075: stable. GDP growth rates: various.

LOVINS ET AL

Lovins et al.
1975 - 2050

Lovins, A.B., L.H. Lovins, F. Krause and W. Bach (1981) *Energy Strategies for Low Climatic Risk* (R&D No 104 92 513). Report for the German Federal Environmental Agency, International Project for Soft-Energy Paths, San Francisco, Cal.

ETA-MACRO
Dynamic opimization

Manne
1975 - 2050

Manne, A.S. (1984) ETA-MACRO Projections. in *Global Carbon Dioxide Emissions - A Comparison of Two models (Contractor Report)*, Electric Power Research Institute, Palo Alto, Cal.

12RT
International Trade Analysis

Manne
1990-2050

Examines the possible impact of carbon emission limits upon future patterns of international trade in energy-intensive basic materials.

Manne, A.S. (1993) *International Trade - the Impact of Unilateral Carbon Emission Limits*. Paper presented at the International Conference on the Economics of Climate. Paris, June.

MERGE
Top-down, intertemporal general equilibrium. Models energy sector, technology selection, technological development, international trade, and is linked to climate change/impact model.

Manne, Mendelsohn and Richels
1990-2200

Latest information on this model

Manne, A., R. Mendelsohn and R. Richels (1993) MERGE-A Model for Evaluating Regio nal and Global Effects of GHG Reduction Policies. *Papers of International Workshop on Integrative Assessment of Mitigation, Impacts and Adaptation to Climate Change*, 13-15 October, 1993, Laxenburg, Austria.

"Business As Usual" Scenario

Population: Exogenous: 1990: 5.3 billion; 2200: 10.4 billion

Economic growth: Endogenous.

Technology: AEEI: 0.5%/annum; backstop technologies assumed.

Energy prices: Endogenous

Energy reserves: Supply elasticities related to future price. Global fossil fuel reserves: Oil: 11.2; Gas: 13.4; Coal: 300 (10_{21} J). Coal resource limits eventually lead to decline in CO2 emissions from fossil fuels under BAU.

Deforestation/Afforestation:

Emissions: Fossil fuel CO2 emissions: 1990: 6.2 billion tonnes; 2200: 20.9 billion tonnes.

Special characteristics: It is an integrated assessment. The energy sector model is linked to reduced forms of climate and impact submodels. International trade in oil, gas and carbon emission permits is assumed.

GLOBAL 2100 Top-down, linked intertemporal equilibrium, Models energy sector, technology selection, technological development, international trade.	Manne and Richels 1990 - 2100

Manne, A.S. and R.G. Richels (1990) Global CO2 Emission Reductions - The Impacts of Rising Energy Costs. EPRI (Electric Power Research Institute), Palo Alto, Cal., USA, *The Energy Journal*, Vol. 12, No. 1, pp. 87-102.

Manne, A.S. and R.G. Richels (1990) CO2 Emission Limits: An Economic Cost Analysis for the USA. *The Energy Journal*, Vol. 12, No. 2, pp. 51-74.

Manne, A.S. and R.G. Richels (1991) Global CO2 Emission Reductions - The Impacts of Rising Energy Costs. *Energy Journal.* Vol. 12, pp. 87-101.

Manne, A.S. and R.G. Richels (1992) *Buying Greenhouse Insurance: The Economic Costs of CO2 Emission Limits.* MIT Press, Cambridge, Mass.

Manne, A. (1992) *Global 2100: Alternative Scenarios for Reducing Carbon Emissions.* Economics Department Working Papers No. 111, OECD, Paris.

Gaskins, D.W., Jnr. and J.P. Weyant (1993) Tentative Conclusions from Energy Modelling Forum Study Number 12 on Controlling Greenhouse Gas Emissions. in Y. Kaya et al. (Eds.) *Costs, Impacts, and Benefits of CO2 Mitigation*, Proceedings of a Workshop held on 28-30 September 1992 at IIASA, Laxenburg, Austria, pp. 235-246.

Latest information on this model

Manne, A.S. and R.G. Richels (1994) The Costs of Stabilizing Global CO2 Emissions- A Probabilistic Analysis Based on Expert Judgements. *The Energy Journal*, January.

"Business As Usual" Scenario

Population: Exogenous;

Economic growth: Endogenous;

Technology: AEEI: 0.7; Backstop technologies assumed

Energy prices: Endogenous;

Energy reserves: Supplies elastic to future prices;

Deforestation/Afforestation:

Emissions: Fossil fuel CO2: 1990: 6 billion tonnes C; 2100: 21.3 billion tonnes C.

Special characteristics: Models key parameters estimated using results from probability poll responses of 22 experts. The above results are based on the average of 50th percentile values for 5 key parameters.

AGE	Manne and Rutherford
5 region intertemporal model	2000-2050
(extension of GLOBAL 2100)	

Manne, A.S. and T.F. Rutherford (1993) International Trade in Oil, Gas and Carbon Emission Rights: An Intertemporal General Equilibrium Model. in Y. Kaya et al. (Eds.) *Costs, Impacts, and Benefits of CO2 Mitigation*, Proceedings of a Workshop held on 28-30 September 1992 at IIASA, Laxenburg, Austria, pp. 315-340.

Examines the impact of both carbon restrictions on future oil prices and leakages if OECD countries adopt unilateral limits for carbon emissions, and quantifies gains from trade in carbon emission rights.

MARKAL-MACRO	Manne and Were
Bottom-up, top-down, linked equilibrium.	1990-2030
Models energy sector and technology	
selection. The detailed bottom-up	
technology of MARKAL is linked to MACRO.	

Latest information on this model

Morris, S.C., J. Lee, W. Marcuse and G. Goldstein (1993) *Cost-effective Energy Strategies for the Reduction of CO2 Emissions in the U.S.* Brookhaven National Laboratory, BNL 48961, U.S.A.

"Business as Usual" Scenario (U.S.A. only)

Population: Exogenous; 1990: 0.25 billion, 2030: 0.303 billion.

Economic growth: Exogenous; Growth rate: 1990-2010: 2.2%/annum, 2010-2030: 1.8%/annum. (1990 dollars)

Technology: initial growth rates that consider non-price-related factors are assumed in each energy demand category. These initial growth rates are then changed in the model by price-elasticity. No backstop technologies assumed.

Energy prices: Only world oil price exogenous. 1995: $US24/bbl., 2030: $US42/bbl. (1990 dollars).

Energy reserves: Supply curves for domestic resources.

Afforestation: Explicitly modelled.

Emissions: U.S.A. only: Fossil fuel CO2: 1990: 1.4 billion tonnes C; 2030: 1.78 billion tonnes C.

AIM
modified Edmonds-Reilly link to bottom-up integration of various models

Matsuoka, Kainuma and Morita
1990-2100

Matsuoka, Y., M. Kainuma and T. Morita (1993) On the Uncertainty of Estimating Global Climate Change. in Y. Kaya et al. (Eds.) *Costs, Impacts, and Benefits of CO2 Mitigation*, Proceedings of a Workshop held on 28-30 September 1992 at IIASA, Laxenburg, Austria, pp. 371-384.

Morita, T. et al. (1993) AIM - Asian-Pacific Integrated Model for Evaluating Policy Options to Reduce GHG Emissions and Global Warming Impacts. *Proceedings of Workshop on Global Warming Issues in Asia, Asian Institute of Technology*, Bangkok, 8-10 September 1993.

Latest information on this model

Morita, T., Y. Matsuoka, M. Kainuma, H. Harasawa and K. Kai (1993) AIM - Asian Pacific Integrated Model for Evaluating Policy Options to Reduce GHG Emissions and Global Warming Impacts. Proceedings of the Workshop on Global Warming Issues in Asia, Bangkok, 8-10 September, 26 pages (to be published as a book from AIT).

"Business As Usual" Scenario

Population: 2100: 11.3 - 13.5 billion.

Economic growth: GNP/capita: ±20% of IPCC reference scenario (1991).
Average GNP/capita growth rate: 2100: 2.9%;

Technology: Endogenous (determined by end-use models).

Energy preices: Endogenous.

Deforestation/Afforestation: estimates deforestation rates based on population increase in each region.

Emissions: Fossil fuel CO2: 1985: 5.1 billion tonnes C; 2100: 11.15 - 39.67 billion tonnes C.

Special characteristics: Under development of impact models which connected to emission and climate models.

G-CUBED
Top-down, dynamic general equilibrium, with macro and multi-sector integration. Models energy sector, technology selection, international trade, land-use/agriculture.

McKibbin and Wilcoxen
1992-2200

McKibbin, W.J. and P.J. Wilcoxen (1993) The Global Consequences of Regional Environmental Policies: An Integrated Macroeconomic, Multi-Sectorial Approach. in Y. Kaya et al. (Eds.) *Costs, Impacts, and Benefits of CO2 Mitigation*, Proceedings of a Workshop held on 28-30 September 1992 at IIASA, Laxenburg, Austria, pp. 247-272.

McKibbin, W.J. and Wilcoxen P.J. (1992) *The Global Costs of Policies to Reduce Greenhouse Gas Emissions.* Brookings Discussion Papers No 97. Brookings Institution, Washington, D.C.

Latest information on this model:

McKibbin, W.J. and P.J. Wilcoxen *G-CUBED: A Dynamic Multi-sector General Equilibrium Model of the Global Economy.* Brookings Institution Discussion Paper No. 98.

"Business As Usual" Scenario

Population: Exogenous; Growth rate: 1990-2000: 1.6%, 2000-2020: 1.3%, 2020-2100: 0.8%, 2100-2200: 0%.

Economic growth: Exogenous in the very long term; endogenous in the short term; 1990-2000: 2.5%, 2000-2020: 2.2%, 2020-2100: 1.7%, 2100-2200: 0.9%. Index: GDP: $22.92 trillion (1990 dollars)

Technology: AEEI: 0; no backstop technologies.

Energy prices: Endogenous; determined by demand and supply of each of the 5 energy sectors.

Energy reserves: Supply elasticities are related to future price; no resource depletion is assumed; current prices depend on current production capacity which depends on expected future prices.

Deforestation/Afforestation: No explicit deforestation scenario as yet, but timber and wood products are modelled as a separate sector.

Other: The Business as Usual scenario is still very preliminary and is concentrated on the U.S.A.

Emissions: Fossil fuel CO2: 1994: 1.35 billion tonnes C; 2030: 1.78 billion tonnes C (both U.S.A.)

Special characteristics: Integration of macro and multi-sectoral modelling; expectations formed rationally; annual time step; treatment of financial markets explicit; foreign capital flows endogenous.

WORLD 3 / World Dynamics — Meadows, Meadows and Randers
World-aggregate system dynamics — 1900 - 2100

Forrester, J. (1971) *World Dynamics.* Productivity Press (formerly Wright-Allen Press), Cambridge, Mass.

Meadows, D.H., D.L. Meadows et al. (1972) *The Limits to Growth.* Universe Books, Potomac Associates, N.Y.

Meadows, D.H., Behrens et al. (1974) *Dynamics of Growth in a Finite World.* Productivity Press (formerly Wright-Allen Press), Cambridge, Mass.

Meadows, D.H., D.L. Meadows, and J. Randers (1992) *Beyond the Limits: Confronting Global Collapse, Envisioning a Sustainable Future.* Chelsea Green Publishing Co., Post Mills, Vt.

Population: 2100: 3.6-14.1 billion; Economic growth: dependent on population and capital investment.

WORLD INTEGRATED MODEL — Mesarovic and Pestel
Regionally-disaggregated model — 1975 - 2025

Mesarovic, M., and E. Pestel (1974) *Mankind at the Turning Point: The Second Report to the Club of Rome.* Dutton, N.Y.

Population: 2100: 7.8-48 billion; Resources: Oil: 666.9 trillion bbl., Gas: 53.3 trillion m3; Coal: 4.1 trillion tonnes.

MARKAL (MARKet ALlocation model) — Morris
Linear program process analysis model

Fishbone, L.G., G. Giesen, G. Goldstein, H.A. Hymmen, K.J. Stocks, H. Vos, D. Wilde, R. Zolcher, C. Balzer and H. Abilock (1983) *User's Guide for MARKAL (BNL/KJA Version 2.0) A Multiperiod, Linear Programming Model for Energy Systems Analysis.* BNL-51701, Brookhaven National Laboratory, USA and KFA, Germany.

Berger, C., R. Dubois, A. Haurie, E. Lessard, R. Loulou and J.P. Waaub (1991) *Canadian MARKAL: An Advanced Linear Programming System for Energy and Environmental Modelling.* GERAD, Montreal.

Model-wide objective function. Minimizes total energy sector costs of meeting exogenously-given energy service demands. No economic effects outside energy sector. No effects of higher cost of energy except introduction of more energy-efficient technologies.

IIASA

Niehaus and Williams
1980 - 2060

Niehaus, F. and J. Williams (1979) Studies of Different Energy Strategies in Terms of Their Effects on the Atmospheric CO2 Concentration. *Journal of Geophysical Research*, Vol. 84, c6, pp. 3123-3129.

Basile, P. et al. (1980) *The IIASA Set of Energy Models: Its Design and Application.* IIASA, Laxenburg.

NKS/GEF-KANSAI
Global econometric

Nikkei
1991-2010

Nihon Keizai Shimbun/Global Environmental Forum-KANSAI (1991) CO2 Emission Charges and the World Economy in 2010 (in Japanese).

Uniform global carbon tax with no recycled tax revenue, to stabilize CO2 at 1990 levels by 2000.

DICE
Integrated, optimal growth model
with intertemporal utility maximization
Dynamic optimization

Nordhaus
1960- indefinite

Nordhaus, W.D. (1979) *The Efficient Use of Energy Resources.* Yale University Press, New Haven, Conn.

Nordhaus, W.D. (1992) *The DICE Model: Background and Structure of a Dynamic Integrated Climate Economy Model of the Economics of Global Warming.* Cowles Foundation Discussion Paper No. 1009, Yale University, New Haven. Conn.

Nordhaus, W.D. (1993) Rolling the DICE: An Optimal Transition Path for Controlling Greenhouse Gases. *Quarterly Journal of Economics* (forthcoming).

Cline, W.R. (1992) *Optimal Carbon Emissions over Time: Experiments with the Nordhaus DICE Model.* Institute for International Economics, Washington, D.C.

Latest information on this model

Science, November, 1993.
Managing The Global Commons. MIT Press, 1994 (forthcoming)

"Business As Usual" Scenario

Population: Exogenous

Economic growth: Endogenous; 1985: US$ 17,890 billion; 2075: US$ 88,217 billion (1990 dollars), Index: Technology level.

Technology: AEEI: 0 - 1.25%/annum; backstop technologies assumed; Harrod neutral and energy (carbon) saving technological change incorporated, and both assumed to tend to 0 exponentially at about 1%/annum.

Energy prices: Endogenous; in reduced form.

Energy reserves: Supply elasticities not related to future price; assumes that exhaustion is irrelevant for the next 200 years.

Deforestation/Afforestation: Built into base assumptions and into mitigation.

Other: A Ramsey model optimizes both investment and climate change mitigation.

Emissions: CO2 and CFCs (as CO2 equiv.): 1965: 4.42 billion tonnes C; 2075: 21.96 billion tonnes C
N2O: 1965: 0.05 million tonnes N2O; 2075: 0.4 million tonnes N2O
CH4: 1965: 0.36 million tonnes CH4; 2075: 0.89 million tonnes CH4

Special characteristics: Complete integration of economy and geophysical side.

NORDHAUS & YOHE	Nordhaus and Yohe
Dynamic optimization	1975 - 2100

Nordhaus, W.D. and G.W. Yohe (1983) Future Paths of Energy and Carbon Dioxide Emissions. in *Changing Climate: Report of the Carbon Dioxide Assessment Committee*, National Academy Press, Washington, D.C.

Nordhaus, W.D. and G. W. Yohe (1983) Probabilistic Forecasts of Fossil Fuel Consumption. in *Changing Climate: Report of the Carbon Dioxide Assessment Committee*, National Academy Press, Washington, D.C.

Population: 2100: 5.66-17.74 billion; GNP growth rate: 1975-2000: 2.3%, 2000-2025: 1.6%, 2025 on: 1%; Resources: Certain economic feasibility: 2.7-3.2 trillion tonnes C equiv., Probable economic feasibility: 11-12.2 trillion tonnes C equiv., Shale oil: 144 trillion tonnes C equiv.

GREEN (GeneRal Equilibrium ENvironmental) OECD	OECD, RAD Division
Top-down, dynamic recursive general equilibrium. Models energy sector, international trade, land use/agriculture.	1985 - 2050

Burniaux, J.M., J.P. Martin, G. Nicoletti and J.O. Martins (1991) *GREEN - A Multi-Region Dynamic General Equilibrium Model for Quantifying the Costs of Curbing Carbon Dioxide Emissions: A Technical Manual.* OECD, Department of Economics and Statistics Working Paper No. 104, OECD/GD(91)119, Resource Allocation Division, OECD, Paris.

Burniaux, J.M., J.P. Martin, G. Nicoletti and J.O. Martins (1991) *The Costs of Policies to Reduce Global Emissions of Carbon Dioxide: Initial Simulation Results with GREEN.* OECD, Department of Economics and Statistics Working Paper No. 103, OECD/GD(91)115, Resource Allocation Division, OECD, Paris.

Burniaux, J.P., G. Nicoletti and J.O. Martins (1992) *GREEN: A Global Model for Quantifying the Costs of Policies to Curb CO2 Emissions.* OECD Economic Studies No. 19.

Oliveira Martins, J., J-M. Burniaux, J.P. Martin and G. Nicoletti (1992) *The costs of Reducing CO2 Emissions: A Comparison of Carbon Tax Curves with GREEN*, Economics Department Working Papers No. 118, OECD, Paris.

Regional and sectorial aggregation, Production sector aggregation, GDP, Technological change, Energy type, supply and price. Full trade links plus tradable permits, oil price endogenous. Market equilibria for all goods: capital, labor, materials, other goods. Consumers choose savings/investment levels. GDP, energy intensity changes determined by interactions throughout the economy. Less detail in energy sector.

Latest information on this model

GREEN-A Multi-Region Dynamic General Equilibrium Model for Quantifying the Costs of Curbing Carbon Dioxide Emissions: A Technical Manual. OECD Working Paper No. 116, Resource Allocation Division, OECD, Paris.

"Business as Usual" Scenario

Population: Exogenous; 1985: 4.821 billion; 2050: 9.982 billion. Growth rates: 1985-90: 1.76%; 2030-2050: 0.65%.

Economic growth: Exogenous; Index: GDP, 1985$; 1985: $12,189 billion, 2050: $59,883 billion. Growth rates: 1985-90: 3.05%, 2030-50: 2.12%

Technology: AEEI: 1%/annum. Assumes back-stop technologies.

Energy prices: Endogenous, determined in the energy exporting regions.

Energy reserves: Supply elasticities not related to future prices. The conversion of yet-to-be found reserves into proven reserves is price sensitive.

Deforestation/Afforestation:

Other: Assumes that energy subsidies are phased out in all regions by 2000.

Emissions: Fossil fuel CO2: 1985: 5.254 billion tonnes C; 2050: 15.66 billion tonnes C.

Institute of Energy Economics, Japan	Ogawa
Edmonds-Reilly Model	1988-2100

Ogawa, Y. (1990) Global Warming Issues and Future Response. *Proceedings of Symposium on Energy and Economics*, 6-7 December 1990, Tokyo (written in Japanese).

Population: 2000: 6.24 billion, 2050: 9.83 billion, 2100: 10.58 billion; Labor Productivity: ~2025: 3% increase per annum; AEEI: 1975~2000: 0.54% per annum, 2000~2025: 0.21 % per annum.

TEC	Okada and Yamaji
Edmonds-Reilly	1975-2025

Okada, K. and K. Yamaji (1993) Simulation Study on Tradable CO2 Emission Permits in Y. Kaya et al. (Eds.) *Costs, Impacts, and Benefits of CO2 Mitigation*, Proceedings of a Workshop held on 28-30 September 1992 at IIASA, Laxenburg, Austria, pp. 341-354.

Maximum afforestation potential and rate of CO2 absorption; Regional afforestation cost functions; Tradable permit flows and prices.

FUGI GLOBAL MODEL 7	Onishi
Linked equilibrium, Econometric,	1990-2000 (2001-2040 in prep.)
Models energy sector, technological development, international trade.	

Kaya, Y. and Y. Suzuki (1974) Global Constraints and a New Vision for Development. *Technological Forecasting and Social Change*, 6(3):4.

Bruckmann, G. (Ed.) (1980) *Input-output Approaches in Global Modeling.* Proceedings of the Fifth IIASA Symposium on Global Modeling, September 26-29, 1977, IIASA, Proceedings Series, Vol. 9, Pergamon Press, N.Y.

Onishi, A. (1991) *FUGI Global Model Simulations of World Economy and CO2 Emissions, 1990-2000.*

CO2 emission stabilization at the 1990 level by 2000. Various assumptions about carbon taxes, ODA, and R&D expenditures.

Latest information on this model

Onishi, A. (1993) "FUGI Global Model 7.0" Economic & Financial Computing. *A Journal of the European Economic and Financial Centre*, Vol. 3, No. 1, Spring, pp. 1-67.

"Business as Usual" Scenario

Population: Endogenous; 1990: 5.296 billion, 2000: 6.226 billion.

Economic growth: GDP Endogenous; 1990: $14,382.9 billion, 2000: $18,217.5 billion (1985 dollars).

Technology: No improvement at the global level.

Energy prices: Endogenous; International oil price will decrease from $22/ bbl. in 1990 to $18/bbl. in 1995 and then gradually increase to $20.6/bbl. in 2000.

Energy reserves: Supplies elastic to future prices;

Deforestation/Afforestation: Under study.

Other: Assumes technological advancement in the use of alternative free energy toward the middle of the 21st century plus a strengthening of energy savings and environment protection technology from the developed to the developing world.

Emissions: Fossil fuel CO2: 1990: 5.72 billion tonnes C; 2000: 7.29 billion tonnes C.

Special characteristics: Classifies the interdependent world into 80 countries and regional groupings and is designed as a policy simulation model of a sustainable world economy within the context of global environmental changes.

CETA (Carbon Emissions Trajectory Assessment) Top-down growth/optimizing model Models energy sector, technology selection, and is linked to climate change/impact model.	Peck and Tiesberg 1990 - 2200

Peck, S.C. and T.J. Tiesberg (1992) CETA: A Model for Carbon Emissions Trajectory Assessment. *The Energy Journal*, Vol. 13, No. 1.

Peck, S.C. and T.J. Tiesberg (1993) Summary of Global Warming Uncertainties and the Value of Information: An Analysis Using CETA. in Y. Kaya et al. (Eds.) *Costs, Impacts, and Benefits of CO2 Mitigation*, Proceedings of a Workshop held on 28-30 September 1992 at IIASA, Laxenburg, Austria, pp. 57-62.

Peck, S.C. (1993) The Implications of Non-linearities in Global Warming Damage Costs. in Y. Kaya et al. (Eds.) *Costs, Impacts, and Benefits of CO2 Mitigation*, Proceedings of a Workshop held on 28-30 September 1992 at IIASA, Laxenburg, Austria, pp. 209-210.

Peck, S.C. and T.J. Tiesberg (1993) Optimal CO2 Emissions Control with Partial and Full World-wide Cooperation: An Analysis Using CETA. *Papers of International Workshop on Integrative Assessment of Mitigation, Impacts and Adaptation to Climate Change*, 13-15 October, 1993, Laxenburg, Austria.

Consumer behaviour, Economic activity, Least cost energy supply mix, New supply technologies, Warming induced damage, Warming rate. Maximizes discounted consumer satisfaction subject to resource and technology constraints. Consumer determines labor supply, consumption, and investment. GDP produced from aggregate production function. Moderate detail in energy sector.

Latest information on this model

Peck, S.C. and Tiesberg T.J. (1993) Global Warming Uncertainties and the Value of Information: An Analysis Using CETA. *Resource and Energy Economics*, Vol. 15, No. 1, March, pp. 71-97.

"Business As Usual" Scenario

Population: Exogenous; Population growth rate: 1990-2100: 1.62%; 2100-2200: 0.0%

Economic growth: Endogenous; 1990: $22.92 trillion; 2200: $445.645 trillion. Index: Gross World Production. 1990 dollars.

Technology: AEEI: 0.25%/annum; backstop technology assumed.

Energy prices: Costs are exogenous; prices are costs plus endogenous shadow prices.

Energy reserves: Oil and gas: 24,740 EJ; coal: 150,000 EJ. No explicit supply elasticities, but there are limits on the rate at which fossil fuel production may be increased or decreased.

Deforestation/Afforestation: Carbon emissions from deforestation are included as part of the exogenously specified emissions from non-energy sources.

Emissions: Fossil fuel CO2: 1990: 5.76; 2120: 47.07; 2200: 1.11 billion tonnes.
Anthropogenic CO2: 1990: 7.29; 2120: 48.91; 2200: 3.54 billion tonnes.
Anthropogenic CH4: 1990: 0.53 million tonnes; 2200: 0.77 million tonnes.
Anthropogenic N2O: 1990: 0. 013 million tonnes; 2200: 0.019 million tonnes.
Anthropogenic CFC 11&12: 1990: 0013 million tonnes; 2012: 0.0; 2200: 0.0.

GLOBAL MACRO-ENERGY - ICF — Pepper
Recursive generalized equilibrium — 1985 - 2100
of global energy markets

ICF (1988) *Global Macro-energy Model.* ICF Incorporated, Fairfax, Va.

Gaskins, D.W., Jnr. and J.P. Weyant (1993) Tentative Conclusions from Energy Modelling Forum Study Number 12 on Controlling Greenhouse Gas Emissions. in Y. Kaya et al. (Eds.) *Costs, Impacts, and Benefits of CO2 Mitigation*, Proceedings of a Workshop held on 28-30 September 1992 at IIASA, Laxenburg, Austria, pp. 235-246.

Population, GNP, Supply technology efficiency improvements, Energy mix, supply, and price.

PERRY-LANSBERG

Perry and Lansberg
1975 - 2025

Perry, H. and H.H. Lansberg (1977) Projected World Energy Consumption. in *Energy and Climate*, National Academy of Sciences, Washington, D.C.

REISTER (GRI)
Edmonds-Reilly

Reister
1975 - 2100

Reister, D.B. (1984) *An Assessment of the Contribution of Gas to the Global Emissions of Carbon Dioxide (GRI-84/0003).* Gas Research Institute, Chicago, Ill.

Reister, D.B. (1984) IEA Projections. in *Global Carbon Dioxide Emissions - A Comparison of Two Models (Contactor Report)*, Electric Power Research Institute, Palo Alto, Cal.

TARGETS
Top-down, system dynamics.
Models energy sector, technological development, land-use/agric., linked to climate change/impact model.

RIVM, Global Dynamics & Sustainable Development Project
1990 - 2100

Latest information on this model

Rotmans, J. et al. (1993) *"Global Change and Sustainable Development: The TARGETS Approach" RIVM Report No. 461502000*, Bilthoven, The Netherlands.

"Business As Usual" Scenario

Population: Endogenous

Economic growth: Endogenous (Index: GNP and industrial output)

Technology: AEEI: 1%; assumes back-stop technologies.

Energy prices: Endogenous. Price is derived from cost (supply-demand disequilibrium) which is in turn based on depletion and learning-by doing dynamics.

Energy reserves: Supply elasticities are (one of the derived) outcomes of the resource dynamics models for solid, liquid and gaseous fuels, respectively.

Deforestation/Afforestation: Deforestation is driven for demand for agricultural lands and wood; afforestation is an exogenous decision on top of natural growth.

Emissions: As yet none have been calculated.

Special characteristics: This model is meant as an integrated systems approach to operationalize the concept of sustainable development from a global perspective for a simulation period up to 2100. The model itself contains several submodels.

ROGNER	Rogner
Edmonds-Reilly	1975 onwards

Rogner, H.H. (1986) Long-Term Energy Projections and Novel Energy Systems. in J.R. Trabalka and D.E. Reichle (Eds.) *The Changing Global Carbon Cycle: A Global Analysis*, Springer-Verlag, N.Y.

ROSE ET AL	Rose et al.
ER	1975 - 2050

Rose, D., M. Miller and C. Agnew (1983) *Global Energy Futures and CO2 Induced Climate Change.* (MITEL 83-015) MIT Energy Laboratory, Massachusetts Institute of Technology, Cambridge, Mass.

IMAGE 1	Rotmans et al.

Rotmans, J., H de Boois and R. Swart (1989) *An Integrated Model for the Assessment of the Greenhouse Effect: The Dutch Approach.* National Institute of Public Health and Environmental Protection, Rijksinstituut voor Volksgezondheid en Milieuhygiaene, The Netherlands.

ROTTY	Rotty
	1975 - 2100

Rotty, R.M. (1979) Energy Demand and Global Climate Change. in W. Bach, J. Pankrath and W. Kellogg (Eds.) *Man's Impact on Climate*, Elsevier Scientific Publishing Co., Amsterdam, The Netherlands.

ROTTY-MARLAND	Rotty and Marland
	1975 - 2100

Rotty, R. and G. Marland (1980) Constraints on Fossil Fuel Use. in W. Bach, J. Pankrath and J. Williams (Eds.) *Interactions of Energy and Climate*, D. Reidel Publishing Co., Boston, Mass.

CTRM (Carbon Rights Trade Model)	Rutherford
Recursive global general equilibrium	1990 -2100

Rutherford, T.F. (1992) *The Welfare Effects of Fossil Carbon Reductions: Results from a Recursively Dynamic Trade Model.* Economics Department Working Papers, No. 112. OECD/GD (92) 89, Paris.

Gaskins, D.W., Jnr. and J.P. Weyant (1993) Tentative Conclusions from Energy Modelling Forum Study Number 12 on Controlling Greenhouse Gas Emissions. in Y. Kaya et al. (Eds.) *Costs, Impacts, and Benefits of CO2 Mitigation*, Proceedings of a Workshop held on 28-30 September 1992 at IIASA Laxenburg, Austria, pp. 235-246.

Consumption, Economic activity, Varied energy supply possibilities, Carbon constraints. Market equilibria for all goods: capital, labor, materials, other goods. Consumers choose savings/investment levels. GDP, energy intensity changes determined by interactions throughout the economy. Less detail in energy sector.

SEIDEL-KEYES	Seidel and Keyes
Edmonds-Reilly	1975 - 2100

Seidel, S. and D. Keyes (1983) *Can We Delay a Greenhouse Warming?* U.S. Environmental Protection Agency, Washington, D.C.

ITF-D4	Shishido
Global econometric	1990-2000

Shishido, S. (1991) *Global Impacts of Carbon Tax: A Simulation Analysis with a Global Econometric Model.* mimeo.

Emphasizes sectoral details of production and trade in industrial countries. CO2 emissions are explained by production and prices. Fossil fuel taxes only in G7 countries.

SIEGENTHALER-OESCHGER	Siegenthaler and Oeschger
	1975 - 2100

Siegenthaler, V. and H. Oeschger (1978) Predicting Future Atmospheric Carbon Dioxide Levels. *Science*, Vol. 199, No. 27, pp. 388-395.

SUNDQUIST-PLUMMER	Sundquist and Plummer
	1975 - 2100

Sundquist, E.T. and L.N. Plummer (1981) Carbon Dioxide in the Ocean Surface Layer: Some Modelling Considerations. in B. Bolin (Ed.) *Carbon Cycle Modelling , SCOPE 16*, John Wiley & Sons, N.Y., pp. 259-269.

IPCC	Swart, Pepper et al.
ASF	1985 - 2100

Swart, R.J., W.J. Pepper et al. (1991) *Emissions scenarios for the IPCC: An Update.* Inter-governmental Panel on Climate Change.

Population: 2100: 10.4 billion; GDP growth rates: 1990-2000: 3.01%; 2075-2100: 1.85%.

UN POPULATION — United Nations

United Nations (1990) *Population Prospects 1990.* United Nations, N.Y.

United Nations (1992) *Long-Range World Population Projections: Two Centuries of Population Growth, 1950-2150.* United Nations Publication, Sales No. E. 92. XIII. 3.

World Population: 2100: 6.4 - 17.6 billion.

GEMINI - DFI/EPA — USEPA
Intertemporal generalized equilibrium — 1990 - 2030
of US energy markets

Scheraga, J.D., D. Cohan, A. Diener, A. Gjerde, S. Haas and A. Smith (1991) *Reassessing the Effectiveness and Cost of Taxes to Reduce CO2 Emissions.* Gemini Notes; Environment Protection Agency, USA.

Gaskins, D.W., Jnr. and J.P. Weyant (1993) Tentative Conclusions from Energy Modelling Forum Study Number 12 on Controlling Greenhouse Gas Emissions. in Y. Kaya et al. (Eds.) *Costs, Impacts, and Benefits of CO2 Mitigation*, Proceedings of a Workshop held on 28-30 September 1992 at IIASA, Laxenburg, Austria, pp. 235-246.

Energy supply and demand technologies, Population, GNP, Energy mix, supply and price, GHG emissions. Equilibrium in energy sector's markets: primary, secondary, electric, etc. No markets for capital, labor, or other nonenergy goods. Reference GDP and/or energy service demand exogenously-given. Price and/or GDP effects on demand through aggregate 'feedback equations'.

EDS (Energy Demand System) - IEA — Vouyoukas and Kouvaritakis
Recursive generalized equilibrium
of global fuel markets

WEC — WEC Commission
Large-scale bottom-up, top-down — 1990-2020 (extensions to 2100)
multi-disciplinary.

Latest information on this model

WEC Commission (1993) *Energy for Tomorrow's World - the Realities, the Real Options and the Agenda for Achievement.* World Energy Council, St. Martins Press, N.Y.

"Reference" Scenario - Case B.

This scenario is an update of the Moderate Economic Growth Scenario in the Report "World Energy Horizons 2000-2020" presented at the WEC Montreal Congress 1989.

Population: 1990: 5.2924 billion, 2020: 8.0917 billion.

Economic growth: GDP 1990: $ 21.0226 billion, $ 2020: 55.700 billion (1985 U.S. dollars).

Technology: Energy intensity: 0.24toe/US$ 1,000 of GDP (1985 dollars); Energy intensity reduction: 1980-1990: -0.82%/annum, 1990-2020: -1.8%/annum. Assumes back stop technologies (including "new renewables"), and high rate of technology transfer.

Primary energy shares: Fossil fuels: 1990: 6810 Mtoe (77%),
2020: 9781 Mtoe (73%), 2050: 57%, 2100: 33%.
Nuclear energy: 1990: 5%, 2020: 6%, 2050: 15%, 2100: 28%.
Renewables: 1990: 18%, 2020: 21%, 2050: 14%, 2100: 26%.

Energy reserves: Ultimately recoverable fossil fuel resources: 4,400 Gtoe; Total nuclear energy resources (known and undiscovered): 17 million tonnes uranium.

Deforestation/Afforestation: Assumes deforestation creates about 2GtC of carbon emissions/annum.

Emissions: Fossil fuel CO2: 1990: 5.5 GtC; 2020: 7.8 GtC; 2050: 11.3 GtC;
2100: 10.8 GtC.
Total CO2: 2020: 8.37 GtC.
Nitrogen: 2020: 26.9 million tonnes.
Sulphur: 2020: 66.0 million tonnes.

Special characteristics: The report is the product of over 500 people, 9 regional working groups, and each scenario is linked to climate change potential.

WHALLEY-WIGLE
Comparative Static, Economic General Equilibrium Model

Whalley and Wigle

Whalley, J.R. and R. Wigle (1990) Cutting CO2 Emissions: The Effects of Alternative Policy Approaches. *The Energy Journal*, Vol. 12, No. 1, pp. 109-124.

Whalley, J.R. and R. Wigle (1990) The International Incidence of Carbon Taxes. in R. Dornbusch and J.M. Poterba (Eds.) *Global Warming: Economic Policy Responses*, MIT Press, Cambridge Mass.

WILLIAMS ET AL
IIASA

Williams et al.
1975 - 2020

Williams, R.H., J. Goldemberg, T.B. Johanson, A.K.N. Reddy and E. Larson (1984) *Overview of an End-Use-Oriented Global Energy Strategy.* Presented at the Hubert Humphrey Institute of Public Affairs Symposium on the Greenhouse Problem: Policy Options, May 29-31, 1984, University of Minnesota, Minneapolis, Minn.