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Lehren aus globalen Energieszenarien

Global long-term energy scenarios: lessons learnt

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Insights in global long-term energy scenarios

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1 Background and content

1.1 Background

This report is the result of task carried out by the author on behalf of IPP. According to the mandate of this task, “the European Fusion Development Agreement (EFDA) is currently developing a multi-regional global energy technologies model. The model will primarily be used to carry out scenario analyses and investigate the potential of fusion to penetrate into future energy markets, in particular electricity. As a preparation for the future use of the model, older studies and other energy models should be analysed. The present study is intended to cover the following issues:

- list of major past and recent studies in the energy field
- selection of central studies
- analysis of the individual studies under the following aspects:
  - client of the study
  - major fiancée
  - organisation or person performing the study
  - background of the study
  - major objective of the study
  - methodology applied
  - major results
  - impact of the study on economic or political decision
- personal experiences of the involved scientist
- conclusion

1.2 Content of the report

The report compiles a few informative texts drawn from the ample literature in the sector. After reporting the main definitions of ‘scenario’ (chapter 2), the report outlines the main characteristics of 13 global long-range energy scenario studies (chapter 3) and their incredibly high results range (Figure 1).

Chapter 4 on Methods illustrates more systematically the problems of building long-term energy scenarios as experienced by the author (section 4.1), the main theoretical approaches used so far (section 4.2) and the main modelling tools through which different theoretical approaches are implemented (section 4.3).

The last chapter illustrates why (sections 5.1 and 5.2) and how (sections 5.3) scenarios have been used so far. It includes some lesson learnt by scenario developers (section 5.4). The personal experience of the author is reported in Annex C. Some suggestions for EFDA socio-economic research related to long-term global energy scenarios and market potential for fusion are reported at the end (section 5.5).

2 What are energy scenarios?[1]

The energy systems group of the International Institute for Applied Systems Analyses (IIASA), one of the dominant actors of the energy scenario scene, states:

> *”In designing scenarios we devise images of the future, or better of alternative futures. Scenarios are neither predictions nor forecasts. Rather each scenario is one alternative image of how the future could unfold. Each is based on an internally consistent and reproducible set of assumptions about the key relationships and driving forces of change that are derived from our understanding of history and the current situation. Often scenarios are formulated with the help of formal models. Most scenarios, (including the ones presented in this study), make one particular assumption about the future: the absence of major discontinuities and catastrophes. These are not only inherently difficult to anticipate, but also offer little policy guidance on managing an orderly transition from today’s energy system, relying on fossil fuels, towards a more sustainable system with more equitable access to energy services.”* And they continue as follows: *”No analysis can ever turn an uncertain future into a sure thing.” “A scenario is an internally consistent and reproducible narrative, describing one possible way the future might unfold”* [IIASA, WEC 1995]

Definitions of scenarios abound in the literature.

> *"Scenarios are a tool for helping us to take a long view in a world of great uncertainty. The name comes from the theatrical term "scenario" – the script for a film or play. Scenarios are stories about the way the world might turn out tomorrow, stories that can help us recognize and adapt to changing aspects of our present environment. They form a method for articulating the different pathways that might exist for you tomorrow, and finding your appropriate movements down each of those possible paths. Scenario planning is about making choices today with an understanding of how they might turn out. In this context the precise definition of "scenario" is: a tool for ordering one’s perceptions about alternative future environments in which one’s decision might be played out. Alternatively: a set of organized ways for us to dream effectively about our own future. Concretely they resemble a set of stories, either written out or often spoken. However, these stories are built around carefully constructed "plots" that make the significant elements of the world scene stand out boldly. This approach is more a disciplined way of thinking than a formal methodology."* [Schwartz, 1996]

> *”The future evolution of the world is formulated in a so-called scenario, a kind of short story of possible futures.”* [Ygdrassil et al., 1989a]

> *”Scenarios can also help in improving the understanding of key relationships among factors that drive future emissions. Scenario outputs are not predictions of the future, and should not be used as such; they illustrate the effect of a wide range of economic, demographic and policy assumptions. They are inherently controversial because they reflect different views of the future.”* [IPCC, 1992]

> *”The LESS alternatives are not forecasts; rather they are self- consistent constructions indicative of what might be accomplished by pursuing particular technical strategies. These alternative paths to the energy future should be regarded as ”thought experiments” exploring the possibilities of achieving deep reductions in emissions….. Moreover there may be other plausible paths that could lead to comparable reductions in emissions”.* [IPCC, 1996a]

[1] The term "scenario" used today in long-term energy-environment studies has a long history. It is taken from a Hollywood approach in which story lines are worked out descriptively and characterized on story boards. It was introduced for military strategy purposes by [Kahn, 1960] as an intellectual exercise and descriptive conceptions of possible futures. Shortly afterwards it was adopted by some multinational companies such as Royal-Dutch Shell for strategic decision making. In the last 15 years they have become more widespread as a tool to aid in planning and policy decision making by governments and ministries, in a variety of areas: from research to public health, from urban planning and transport to energy infrastructure. The descriptions can be fleshed out to any degree, including numerical analysis.

"Virtually all existing efforts are "surprise-free", devoid of the wars, depressions, plagues and other "breakpoints" that have so influenced history." Anderberg (1989) states: "Through frequent use the meaning of scenario seems to have become increasingly broad and vague. Wilson (1978) first describes scenarios as "essential stories", then defines a scenario as "an exploration of alternative futures" or an "outline of one conceivable state of affairs given certain assumptions." He furthermore raises the important question: "Is a scenario a path into the future or is it a future state of the world?" [Toth, 1989]

Scenarios therefore describe hypothetical processes, sequences of events that could develop over a period of time.

"The design of scenarios, i.e. the configuration of the development of important drivers in consistent way, […] can be considered a form of art" (European Commission, Shared analysis project)

The above definitions are in clear contrast with any idea of "prediction" or "forecast", as there are non scientific bases to predict future in socio-economic sciences. Furthermore, it is radically different from the idea of traditional business forecasting, inasmuch as scenarios present alternative images of the future, rather than merely projecting the trends of the present. As [Davis, 1998] puts it:

"Many have tried to understand the future purely through prediction, even though the record to date is poor. Forecasters extrapolate from the past, imposing the patterns they see in the past onto the future, and tend to neglect the oft quoted statement that 'a trend is a trend until it bends'. And it is the bends that are generally of most interest to us because it is the bends that carry the most risk or offer the greatest opportunities."

Useful as they are, forecasts present a fundamental danger: they give us the illusion of certainty and leave us ill equipped to understand uncertainty, accept ignorance and tackle risk. In fact one of the most useful characteristics of scenarios is that they are explicitly designed to explore, and thus integrate, radical departures from trend, breakdowns in the system, technological breakthroughs, and major shifts in human behaviour or changes in institutional rules. Precisely these four issues are the major axes along which discontinuities are explored with the greatest interest in the energy-environment field.

"The end result [of a present scenario exercise] is not an accurate picture of tomorrow, but better decisions today [about the future]." [Schwartz, 1996]

Summarising: given the impossibility to know events that have not yet unfolded, scenarios are the best tools invented so far to explore the future and discuss how to shape it with a rational discourse.

According to [Anderberg, 1989] "scenario is a term that has become increasingly popular. One major driving force to implement scenarios into the energy scene was the oil shock of 1973. This historic event triggered a great debate with regard to funding of energy-related institutions and research groups; it also affected the range and quality of publications related to the future energy supply." But we still do not know what a scenario really is, and what it is for. There is no established doctrine on how to create, present or use scenarios."[2]

[2] Most quotes are taken from [IEA/OECD, 2003] and [Craig et al., 2002].

3 Outline of some scenario studies

3.1 A list

Table 1 and Table 2 list relevant past and recent long term energy scenarios. Although incomplete, they give a picture of how many scenarios have been produced, how many scenario building tools have been used, how many groups have been involved – some quite large – and how many countries have contributed.

Table 1: Fusion in energy scenarios: an overview [Gazso, 2001]

Publication:	Year	Scenario:	Time Horiz.	Code	Publication:	Year	Scenario:	Time Horiz	Code
NEA	1998	Continued Nuc.Growth	2050	0	Johansson et al.	1993	RIGES	2050	0
		Phase Out	2050	0	WEC 1993	1993	general		1
		Stagnation, then Revival	2050	0			A	2020	0
Langniß et al.	1997	DLR	2100	0			B	2020	0
Dessus	1996	NOÉ/NOES	2100	3			B1	2020	0
EC, DG XVII	1996	Conventional Wisdom	2020	0			C	2020	0
		Battlefield (only EU)	2020	0	IPCC	1992	IS92a	2100	0
		Forum (only Europe)	2020	0			IS92b	2100	0
		Hypermarket (only EU)	2020	0			IS92c	2100	0
IPCC	1996	General		4			IS92d	2100	0
		LESS-BI (Biomass)	2100	0			IS92e	2100	0
		LESS-NI (Nuclear)	2100	5/7			IS92f	2100	0
		LESS-NGI (Nat. Gas)	2100	0			Sa90	2100	0
		LESS-CI (Coal Intens)	2100	0	IPCC (RSWG)	1990	HE (business as usual)	2100	0
		LESS-HD(High Dem)	2100	0			LE(low emissions)	2100	0
top down		LESS case1	2100	0			CP(control policies)	2100	0
variants:		LESS case2	2100	0			AP(accelerated politics)	2100	0
(see Edmonds		LESS case3	2100	0	Anderberg	1989	Big Shift	2075	0
et al. 1994)		LESS case4	2100	0			Big Load	2075	0
		LESS case5	2100	0			Rurban Arcadian Drift	2075	0
		LESS case6	2100	0	Goldemberg et al.	1987	general	2020	3
IIASA/WEC95	1995	General		2			Base Case	2020	0
		A1	50+	0	Edmonds/Reilly	1985		2100	2/4
		A2	50+	0	Edmonds/Reilly	1983		2050	0
		A3	50+	0	Nordhaus/Yohe	1983		2100	0
		B1	50+	0	WEC.1983	1983	rosy	2020	0
		C1	50+	0			grey	2020	0
		C2	50+	0	Colombo/Bernadini	1982	Low Energy Growth	2030	0
Shell	1995	Sustained Growth	2060	6	Lovins et al.	1981	High Efficiency	2030	0
		Dematerialization	2060	6	IIASA/WEC	1981	general		2
Duchin, Lange	1994	OCF	2020	0			High	2030	0
		OCF/HN (Hydro-Nuc.)	2020	0			Low	2030	0
		OCF/S (Solar)	2020	0	CEQ	1980	general	2000	0
		OCF/CI (China, India)	2020	0	Marchetti/Nakic.	1979		2050	8
		OCF/CIHN (CI and HN)	2020	0					

Codes: 0=not mentioned; 1=there should be research; 2=feasibility; 3=compared R&D fundings; 4=unlimitedness; 5=role compared to fast breeder; 6=surprise; 7=reducing safety, waste&proliferation hazards; 8=hypothetical SOLFUS; 9=tokamaks/ITER not useful for the development of practical fusion power; 10=included.
2050+ = both 2050 and 2100 time horizons are considered.

Table 2a: List of the world scenarios (see the IPCC SRES web site [IPCC DB, 1999-2006])

ID	Authors	Reference	Year	Source
12RT/IPCC94		From Dr. Grubler		IPCC94
ADLMN94	Center for Energy & Environmental Policy Research, MIT	World Oil History, March 1994.	1994	IEW Poll Results, 1995
ADLMN95	Center for Energy & Environmental Policy Research, MIT	M.A.Adelman, "The Genie Out of the Bottle: World Oil Since 1970", Cambridge, Massachusetts, MIT Press, 1995.	1995	IEW Poll Results, 1997
AGE/IPCC94	Manne et al.		1993	IPCC94
AIM/EMF14	Matsuoka et al.	Energy Modeling Forum (EMF) 14	1997	EMF14
AIM/EMF16	Nat. Institute for Env. Studies(NIES-Japan), Kyoto University	Energy Modering forum 16, 1998 August, Stanford University	1998	EMF16, 1998
AIM/IPCC94	Matsuoka et al.		1993	IPCC94
AIM/pSRES	Matsuoka et al.	post SRES data, 2000	2000	unpublished data
AIM/SRES	Matsuoka et al.	SRESdata, 2000	2000	http://sres.ciesin.org/
AIM_pSRES2001	Matsuoka et al.	Post-SRES for IPCC-TGCIA 2001	2002	unpublished data
AIM94	Matsuoka et al.	Matsuoka et al., 1994: Scenario analysis of global warming using the Asian-Pacific integrated model, Energy Policy, 23(4/5), 357-372.	1994	IEW Poll Results, 1997
AIM95	Matsuoka et al.	Prof. Matsuoka's unpublished data file	1996	unpublished data
AIM96	Matsuoka et al.	Matsuoka et al., 1994: Scenario analysis of global warming using the Asian-Pacific integrated model, Energy Policy, 23(4/5), 357-372.	1996	EMF14
AIM97	Matsuoka et al.	Prof. Matsuoka's unpublished data file	1997	unpublished data
AMOCO	Amoco Corporation	"World Oil and Energy Outlook", May 1993.	1993	IEW Poll Results 1996
Anderson/IPCC94	Bird		1992	IPCC94
ASF/pSRES	ICF Corporation, USA	post SRES data, 2000	2000	unpublished data
ASF/SRES	ICF Corporation, USA	SRESdata, 2000	2000	http://sres.ciesin.org/
ASF_pSRES2001	ICF Corporation, USA	Post-SRES for IPCC-TGCIA 2001	2002	unpublished data
Bach/IPCC94	Bach		1991	IPCC94
CETA/EMF14	Peck and Teisberg	Energy Modeling Forum (EMF) 14	1997	EMF14
CETA/IPCC94	Peck et al.		1993	IPCC94
CETA95	Peck and Teisberg	CETA: A Model for Carbon Emissions Trajectory Assessment, Energy J, Vol. 13, No. 1(1992), pp 55-77. Projection submitted June 1995.	1995	IEW Poll Results, 1996
CETA95/EMF	Peck and Teisberg	Peck and Teisberg, 1995: Optimal CO2 control policy with stochastic losses from temperature rise, Climatic Change, 31, 19-34.	1995	IEW Poll Results, 1997
Challenge/IPCC94				IPCC94
CRPS	Hammitt, J.K.	Hammitt, J.K., 1995: Outcome and value uncertainties in global change policy, Climatic Change, 30(2), 125-145.	1995	IEW Poll Results, 1997
CRPS/EMF14	Hammitt, J.K.	Energy Modeling Forum (EMF) 14	1997	EMF14
CRTM/IPCC94	Rutherford		1992	IPCC94
DICE	Nordhaus, W.D.	Nordhaus, W.D., 1994: Managing the global commons: The economics of the greenhouse effect, MIT Press, Cambridge, MA.	1994	IEW Poll Results, 1997
DICE/EMF14	Nordhaus, W.D.	Energy Modeling Forum (EMF) 14	1997	EMF14
DICE/IPCC94	Nordhaus et al.		1993	IPCC94
DNE21/98	Y.Fujii and K.Yamaji	Assessment of Technological Options in the Global Energy System for Limiting the Atmospheric CO2 Concentration, Env. Economics & Policy Studies, 1, pp.113-139 (1998)	1998	Environmental Economics and Policy Studies, 1998
DRI	DRI	World Energy Forecast Report – December 1993	1993	IEW Poll Results, 1995
ECS92/IPCC94	ECS	1992 LP model, read from Dr. Naki	1992	IPCC94
EIA94	EIA/U.S. Department of Energy	International Energy Outlook, 1994.	1994	IEW Poll Results, 1995

Table 2b: List of the world scenarios (2/5)

ID	Authors	Reference	Year	Source
EIA96	EIA/U.S. Department of Energy	International Energy Outlook, 1996 (May 1996).	1996	IEW Poll Results, 1997
EIS/IPCC94				IPCC94
EMF14 Assumptions	EMF14	Energy Modeling Forum (EMF) 14	1997	EMF14
EPA/IPCC94	Global US			IPCC94
EPA98	Sankovski, Alexei	ICF's unpublished data file.	1998	ICF's unpublish data.
ERM/IPCC94	Edmonds et al.		1991	IPCC94
ESCAPE/IPCC94	Rotmans et al.		1994	IPCC94
EU	European Commission DG XVII	European Energy to 2020: A scenario approach Energy in Europe, special issue, forthcoming, submitted in December 1995.	1995	IEW Poll Results, 1997
FUGI7.0/IPCC94	Onishi.		1993	IPCC94
FUND	Tol,R.S.J.	Tol,R.S.J., 1995: The climate fund sensitivity, uncertainty, and robustness analyses, W-95/02, Institute for Environmental Studies, Vrije Universiteit, Amsterdam.	1995	IEW Poll Results, 1997
FUND/EMF14	Tol,R.S.J.	Energy Modeling Forum (EMF) 14	1997	EMF14
GLOBAL2100/93	Alan Manne and Leo Schrattenholzer	"Harmonized Conventional" CHALLENGE Scenario Alan Manne and Leo Schrattenholzer	1993	IEW Poll Results, 1996
GLOBAL2100/IPCC94	Manne et al.		1994	IPCC94
GREEN	GREEN	submitted to CHALLENGE, July 1993.	1993	IEW Poll Results, 1996
GREEN/IPCC94	OECD			IPCC94
GREEN91/IPCC94	Burniaux at al.		1991	IPCC94
GREEN92/IPCC94	Burniaux at al.		1992	IPCC94
HCRA	Hammitt, J.K.	Hammitt, J.K., 1995: Harvard Center for Risk Analysis	1995	IEW Poll Results, 1997
HCRA/EMF14	Hammitt, J.K.	Energy Modeling Forum (EMF) 14	1997	EMF14
IAEA	IAEA	Energy, Electricity, and Nuclear Power Estimates for the Period up tp 2015, July 1995.	1995	IEW Poll Results, 1997
ICAM2	Dowlatabadi, H.	Dowlatabadi, H., 1995: Integrated assessment climate assessment model 2.0, technical documentation, Department of Engineering and Public Policy, Carnegie-Mellon University, Pittsburgh.	1995	IEW Poll Results, 1997
ICAM2/EMF14	Dowlatabadi, H.	Energy Modeling Forum (EMF) 14	1997	EMF14
IEA	IEA	World Energy Outlook, 1994.	1994	IEW Poll Results, 1997
IEA/IPCC94	IEA	Energy is calculated with EMF Base Case, Table A1 in Aug.1991	1991	IPCC94
IEA92/IPCC94	Vouyoukas et al.		1992	IPCC94
IEA93/IPCC94	Vouyoukas et al.		1993	IPCC94
IEA98/WEO	Dr. Fatih Birol	IEA's unpublished data file.	1998	IEA's unpublish data
IEW/IPCC94	IEW		1991	IPCC94
IIASA/EMF14	IIASA	Energy Modeling Forum (EMF) 14	1997	EMF14
IIASA/GECCP	IIASA	Yuri Sinyak, January 1992.	1992	IEW Poll Results, 1995
IIASA/IPCC94	Rogner		1983	IPCC94
IIASA/WEC98	IIASA & WEC	World Energy Council, 1998.	1998	IIASA's unpubli-shed data file.
IIASA96		Population data form Mr. Stuart Gaffin	1996	unpublished data
IIASAWEC	IIASA & WEC	WEC/IIASA: Global energy perspectives to 2050 & beyond, World Energy Council, London, 1995.	1995	WEC
IMAGE/pSRES	RIVM	post SRES data, 2000	2000	unpublished data
IMAGE/SRES	RIVM	SRESdata, 2000	2000	http://sres.ciesin.org/

Table 2c: List of the world scenarios (3/5)

ID	Authors	Reference	Year	Source
IMAGE_pSRES2001	RIVM	Post-SRES for IPCC-TGCIA 2001	2002	unpublished data file
IMAGE2.0	Alcamo, J.	Alcamo, J. (ed.), 1994: Image 2.0: Integrated modeling of global climate change, Kluwer, Dordecht, The Netherlands.	1994	IEW Poll Results, 1997
IMAGE2.1	RIVM	1. Alcamo, J., G.J.J. Kreileman, J.C. Bollen, G.J. van den Born, R. Gerlagh, M.S. Krol, A.M.C. Toet and H.J.M. de Vries, 1996. " Baseline scenarios of global environmental change." Global Environmental Change. 6(4):261-303. 2. Leemans, R., A. van Amstel, C. Battjes, E. Kreileman and S. Toet, 1996. " The land cover and carbon cycle consequence of large-scale utilization's of biomass as an energy source." Global Environmental Change. 6(4):335-377. 3. Alcamo, J. and G.J.J. Kreileman, 1996. " Emission scenarios and global climate protection." Global Environmental Change. 6(4):303-334. 4. Posch, M., J.P. Hettelingh, J. Alcamo and M. Krol, 1996. " Integrated scenarios of acidification and climate change in Asia and Europe.' Global Environmental Change. 6(4):375-394.	1996	
IPCC90/IPCC94	IPCC1990, 1990EIS Ref		1990	IPCC94
IS92	J. Leggett, W.J. Pepper and R.J. Swart	1. J. Leggett, W.J. Pepper and R.J Swart, "Emissions Scenarios for the IPCC: an Update", Climate Change 1992: The Supplementary Report to The IPCC Scientific Assessment, 68-95, 1992. 2. W. J. Pepper, R.J. Leggett, R.J. Swart, J. Wasson, J. Edmonds and I. Mintzer, " Emission Scenarios for the IPCC - and Update : Backgroud Documentation on Assumptions, Methodology, and Results", US EPA, Washington, D.C.	1992	IPCC
ITF-D4/IPCC94	Shishido		1992	IPCC94
LDNE/pSRES	Tokyo Univ., Japan	post SRES data, 2000	2000	unpublished data file
LDNE_pSRES2001	Tokyo Univ., Japan	Post-SRES for IPCC-TGCIA 2001	2002	unpublished data file
LYNCH	Center for International Studies, MIT, MOE	Submitted to the IEW, January 1994.	1994	IEW Poll Results, 1997
MANNE	Alan S. Manne	Alan S. Manne, "International Trade - the Impact of Unilateral Carbon Emission Limits", July 1993.	1993	IEW Poll Results, 1996
Manne&Richels/IPCC94			1992	IPCC94
MARIA/EMF14	Mori Shunsuke	Energy Modeling Forum (EMF) 14	1997	EMF14
MARIA/pSRES	Mori Shunsuke	post SRES data, 2000	2000	unpublished data
MARIA/SRES	Mori Shunsuke	SRESdata, 2000	2000	http://sres.ciesin.org/
MARIA_pSRES2001		Post-SRES for IPCC-TGCIA 2001	2002	unpublished data
MARIA95	Mori Shunsuke	Mori, S., Long-term interactions among economy, environment, energy, and land-use changes - An extension of MARIA Model, Technonical Report IA-TR-95-04, Science University of Tokoy, Japan	1997	
MARIA95/IEW	Mori Shunsuke	Mori, S., 1995: Long-term interactions among economy, environment, energy, and land-use changes - An extension of MARIA (Multiregional Approach for Resource and Industry Allocation Model), Technical Report IA-TR-95-04, Science University of Tokyo, Japan.	1995	IEW Poll Results, 1997
MERGE/EMF14	Manne and R.G. Richels	Energy Modeling Forum (EMF) 14	1997	EMF14
MERGE/IEW96	MERGE model	MERGE; A.S. Manne and R.G. Richels, "The Greenhouse Debate: Economic Efficiency, Burden Sharing and Hedging Strategies", The Energy Journal, vol. 16, no. 4, pp. 1-37, 1995.	1995	IEW Poll Results, 1996
MERGE/IEW97	A.S.Manne and R.G. Richels	Manne,A.S., and R.G. Richels, 1995: "The Greenhouse Debate: Economic Efficiency, Burden Sharing and Hedging Strategies", The Energy Journal, 16 (4), 1-37.	1995	IEW Poll Results, 1997

Table 2d: List of the world scenarios (4/5)

ID	Authors	Reference	Year	Source
MERGE/IPCC94	Manne et al.		1993	IPCC94
MERGE3.0	A.S.Manne and R.G. Richels	A.S.Manne and R.G. Richels, MERGE 3, preliminary reference case results, January 1997.	1997	IEW Poll Results, 1997
MERGE94	A.S.Manne and R.G. Richels	Noncooperative scenario - no carbon limitations, November 1994.	1994	IEW Poll Results, 1995
MESSAGE/pSRES	IIASA	post SRES data, 2000	2000	unpublished data
MESSAGE/SRES	IIASA	SRESdata, 2000	2000	http://sres.ciesin.org/
MESSAGE_pSRES2001	IIASA	Post-SRES for IPCC-TGCIA 2001	2002	unpublished data file
MethaneEconomy/IPCC94	METHAN E.		1988	IPCC94
MINICAM/EMF14	Edmonds et al.	Energy Modeling Forum (EMF) 14	1997	EMF14
MiniCAM/pSRES	Edmonds et al.	post SRES data, 2000	2000	unpublished data
MiniCAM/SRES	Edmonds et al.	SRESdata, 2000	2000	http://sres.ciesin.org/
MiniCAM_pSRES2001	Edmonds et al.	Post-SRES for IPCC-TGCIA 2001	2002	unpublished data
MINICAM94	Edmonds et al.	Design for the global change assessment model, proceedings of the International Workshop on Integrative Assessment Mitigation, Impacts, and Adaptation to Climate Change, IIASA, Laxenburg, Austria, 13-15 October.	1994	IEW Poll Results, 1997
MINICAM97	Edmonds et al.		1997	
Mintzer/IPCC94	WRI		1987	IPCC94
MIT	Center for Global Change Science and Center for Energy and Environmental Policy Research	MIT,1994: Center for Global Change Science and Center for Energy and Env. Policy Research, "Joint program on the science and technology of global climate change". Cambridge, MA.	1994	IEW Poll Results, 1997
MIT/EMF14	Center for Global Change Science and Center for Energy and Environmental Policy Research	Energy Modeling Forum (EMF) 14	1997	EMF14
MR/IPCC94	Manne et al.		1991	IPCC94
N-Y/IPCC94			1983	IPCC94
NEA	NEA,Nuclear Energy Agency	Nuclear energy data and other non-published documents, May 1994.	1994	IEW Poll Results, 1997
Nordhaus/IPCC94	Yoh		1983	IPCC94
NSUWG	NEPA(China), SPC (China), UNDP, GEF	China: Issues and Options in GHGs Emission Control, Summary Report, December 1994; transscribed at IIASA by Wei Zhihong.	1994	IEW Poll Results, 1997
NWEAR21/EMF14	Yasumasa Fujii et al.	Energy Modeling Forum (EMF) 14	1997	EMF14
NWEAR21/IEW95	Yasumasa Fujii et al	Yasumasa Fujii et al., "Global Energy System and CO2 Emissions Control Policies", June 1993 (revised March 1994).	1994	IEW Poll Results, 1995
NWEAR21/IEW97	Yasumasa Fujii et al.	Yasumasa Fujii et al., "Global Energy System and CO2 Emissions Control Policies", June 1993 (revised March 1994).	1994	IEW Poll Results, 1997
ODELL	Peter Odell	Global Energy Prospects, 1994.	1994	IEW Poll Results, 1997
Ogawa/IPCC94	Ogaswa		1990	IPCC94
OWEM/IEW95	OPEC World Energy Model	Submitted to CHALLENGE, September 1993.	1993	IEW Poll Results, 1995
OWEM/IEW97	OPEC World Energy Model	Submitted to the IEW Poll, December 1995.	1995	IEW Poll Results, 1997
PAGE/EMF14		Energy Modeling Forum (EMF) 14	1997	EMF14
PEF/EMF14		Energy Modeling Forum (EMF) 14	1997	EMF14
PEFM	Cohan et al.	Cohan et al., 1994: The global climate policy evaluation framework, proceedings of the 1994 A&WMA Global Climate Change Conference: Phoenix, 5-8 April, Air & Waste Management Association, Pittsburgh.	1994	IEW Poll Results, 1997
PETRO/pSRES	Statisitcs Norway	post SRES data, 2000	2000	unpublished data

Table 2e: List of the world scenarios (5/5)

ID	Authors	Reference	Year	Source
PETRO_pSRES 2001	Statisitcs Norway	Post-SRES for IPCC-TGCIA 2001	2002	unpublished data file
RAND/EMF14		Energy Modeling Forum (EMF) 14	1997	EMF14
RICE	Nordhaus et al.	Nordhaus and Yang, 1995: RICE: A regional dynamic general equilibrium model of optimal climate change policy, Yale University Press, New Haven, CT.	1995	IEW Poll Results, 1997
RICE/EMF14	Nordhaus et al.	Energy Modeling Forum (EMF) 14	1997	EMF14
RICE99	Nordhaus	Prof. Nordhaus's unpublished data file	1999	unpublished data file
RIGES/IPCC94				IPCC94
Rogner/IPCC94	Rogner		1986	IPCC94
SGM97	Jay Edmonds, Ronald D Sands	Dr. Ronald D Sands's unpublished data file	1997	unpublished data file
SGM99	Jay Edmonds, Ronald D Sands	Prof. Sands's unpublished data file	1999	unpublished data file
TARGET	RIVM	Rotmans, J., 1995: TARGETS (Tool to Assess Regional and Global Environmental and Health Targets for Sustainability) in transition, RIVM Report, Rijksinstitut Voor Volksgezondheid En Milieuhygiene (National Institute for Public Health and Environment), Bi	1995	IEW Poll Results, 1997
TARGETS/EMF14	RIVM	Energy Modeling Forum (EMF) 14	1997	EMF14
TEC/IPCC94	Okada et al.		1991	IPCC94
UN 92 LR		Population data form Mr. Stuart Gaffin	1996	unpublished data
UN 96		Population data form Mr. Stuart Gaffin	1996	unpublished data
US Cens.Bur.		Population data form Mr. Stuart Gaffin	1996	unpublished data
WEC	WEC	World Energy Council, September 1993.	1997	IEW Poll Results, 1996
WEC/IPCC94	WEC	World Energy Council REFERENCE, 1993	1993	IPCC94
World Bank		Population data form Mr. Stuart Gaffin	1996	unpublished data
WorldBank/IPCC94	Anderson et al.		1992	IPCC94
WorldScan/EMF 14	Johannes Bollen, Arjan Gielen	WorldScan by the CPB Netherlands Bureau for Economic Policy Analysis	1997	EMF14
WorldScan/pSR ES	Johannes Bollen, Arjan Gielen	post SRES data, 2000	2000	unpublished data
WorldScan_pSR ES2001	Johannes Bollen, Arjan Gielen	Post-SRES for IPCC-TGCIA 2001	2002	unpublished data
YOHE/EMF14	Gary Yohe, Wesleyan University	Energy Modeling Forum (EMF) 14	1997	EMF14
YOHE/IEW97	Gary Yohe, Wesleyan University	Yohe, G., 1995: Exercises in hedging against extreme consequences of global change and the expected value of information, Department of Economics, Wesleyan University, CT.	1995	IEW Poll Results, 1997
YOHEU	Gary Yohe, Wesleyan University	Integrated Assessment Model, results submitted to the IEW Poll, December 1995.	1995	IEW Poll Results, 1997

AIM	Asian-Pacific Integrated Model
ASF	Atmospheric Stabilization Framework
CETA	A Model for Carbon Emissions Trajectory Assessment
CRPS	Climate Research and Policy Synthesis Model
DICE	Dynamic Integrated Climate and Economy Model
DNE21	Dynamic New Earth 21 Model
EMF	Stanford Energy Modelling Forum
FUND	Climate Framework
ICAM	Integrated Climate Assessment Model
MiniCAM	MiniGlobal Change Assessment Model
OWEM	OPEC World Energy Model
PEFM	Policy Evaluation Framwork Model
RICE	Regional DICE
YOHE	Connecticut Model

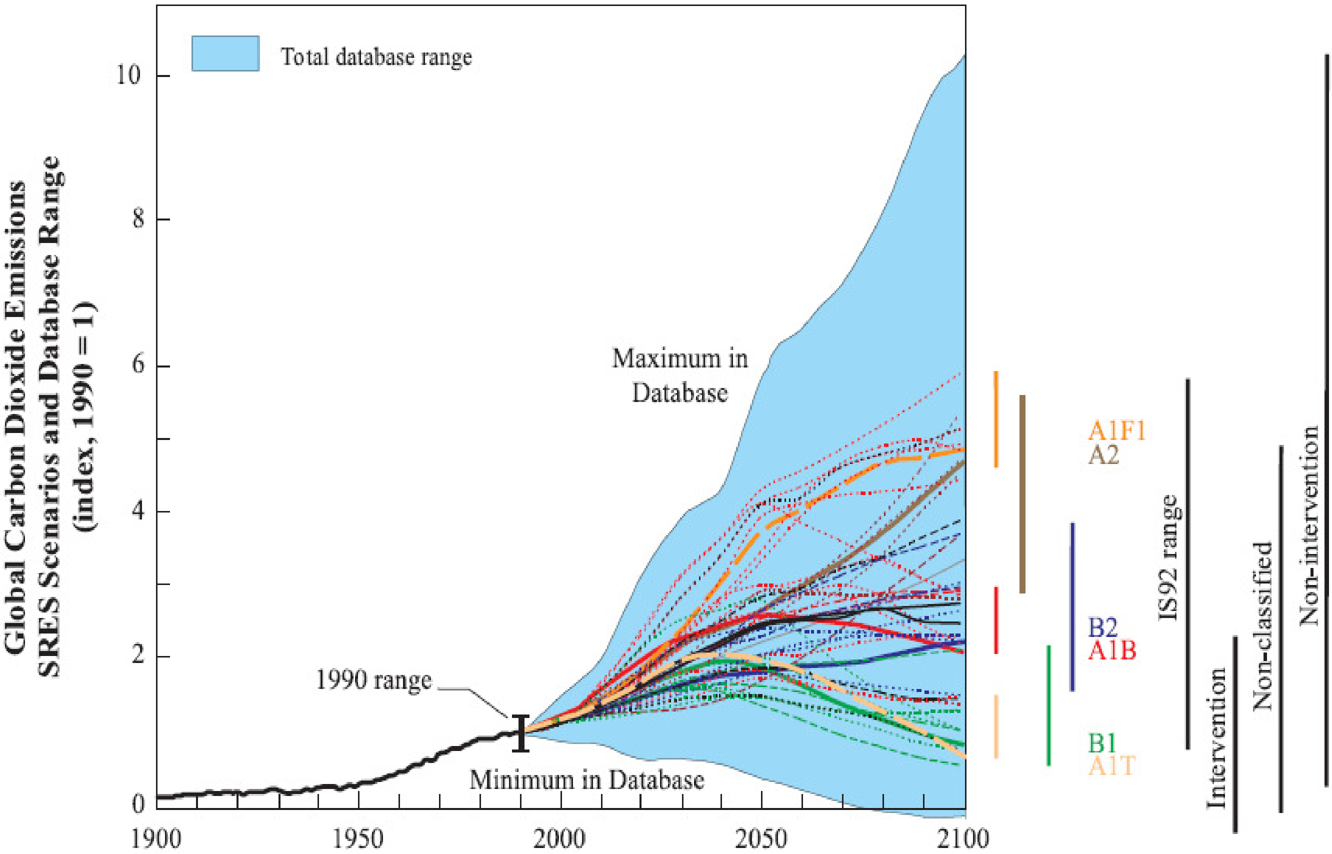

Figure 1: Range of global CO2 Emissions in [IPCC/SRES, 2001]

Since each group uses a different method and starts from independent exogenous inputs, scenarios portray divergent energy projections, as shown by Figure 1. This shows pictorially that scenario building is a subjective and judgemental exercise.

3.2 A review of some relevant scenario studies

The importance of documenting and reviewing long term global energy scenarios was first understood by Professor Alan Manne (Stanford) in 1980[3]. With the support of Leo Schrattenholzer (IIASA) they started collecting and discussing all available global energy scenarios at the yearly International Energy Workshop. Hundreds of global scenarios have been discussed in the 27 editions of IEW so far.

More recently the importance of this exercise was recognised by the Intergovernmental Panel for Climate Change (IPCC). The experts responsible for the preparation of the Special Report of Emission Scenarios [IPCC/SRES, 2001] started collecting all sort of global long term scenarios with information on GHG emissions. The exercise continues to date (see Table 2 above). Nearly 150 studies, most of which including several scenarios, have been collected so far for the next report on emission scenarios.

[3] See: http://www.iiasa.ac.at/Research/ECS/IEW2007/index_1stannouncement.html

Table 3: Base characteristics of 13 scenario studies

No.	Study	year	Funded by	tool	N. scen
1	Club Rome	1971	VW foundation	System Dynamics	12
2	Shell	1972 →	Shell	Quali-quantitative	2
3	WAES	1974-77	National companies	Econometric-LP	5
4	IIASA	1973-81	IIASA	LP at al.	2
5	IPSEP	1987-97	NL Min. of Health	Simulation	4
6	GSG	1995-97	SEI	Simulation	6
7	MILL.	1996-99	ACUNU	Delphi, quail-quan	3
8	WBCSD	1997 -	Corporations	Quali-quantitative	3
9	WEC/IIASA	→	NGO	MESSAGE et al.	6
10	IEO	→	US-EIA	SAGE	3
11	WEO	→	IEA	Econometric-LP	2
12	ETP	2006 →	IEA-UK at al.	MARKAL-15 reg.	7
13	ITPS	1997 →	EC	POLES	

Some long term global energy scenarios are briefly characterised in the following pages. The first group includes the earliest scenario assessment, up to 1984. The second group includes scenarios prepared for the purpose of demonstrating sustainability. The third group includes scenarios that appear, or are intended to appear regularly. They have been chosen for their perceived importance and impact, as well as because they represent all the most significant points of view in the matter and they make use of the most significant scenarios methodologies available so far (see Table 3).

The characterization is not simple, because each scenario study is described in reports mostly longer than thousand pages. To the extent possible each group is characterised on the basis of such elements as the purpose, the time horizon considered, the construction process and the type of tools used. The review indicates wherever possible the main drivers and trends identified, and some of the quantitative elements (population and income growth, energy demand, technologies used, GHG emissions, resulting concentrations).

3.2.1 First assessments

3.2.1.1 The Club of Rome and the Limits of Growth

“The Limits to Growth” study [Meadows, 1972] was commissioned in 1968 to MIT professors Dennis Meadows and Jay Forrester by the Club of Rome. The Club of Rome was an informal group of businessmen, policy makers and scientist of several countries, headed at the time by Aurelio Peccei. The work was funded by the Volkswagen Foundation (Germany). The report was reissued with the more alarming title: “Beyond the limits” on its twentieth anniversary [Meadows, 1992]. It included new analyses and commentary about its history. It was followed by “Limits to Growth: the 30-year update” in 2004 [Meadows, 2004.

The report focused on population increases, resource depletion and decreasing productivity – owing to environmental pollution. “The Limit to Growth” asserted that the global constraints on resource use and environment emissions would greatly influence the future of our planet in the XXI century. It warned as well that humankind could be forced to shift large amount of production factors – capital and labour – to combat those constraints, up to a level that would reduce the average welfare in the course of the XXI century. The report did not specify what resources or emissions would limit the growth. The 1992 update was confirming the 1972 message, but put forward a new important result: the authors asserted the humankind had already gone beyond the limits of our planet sustainability.

The team of system analysts employed a classic system dynamics or bucket model approach[4], implemented through the World3 computer model [Forrester, 1971], in order to produce the 12 scenarios included in the original report.

Criticisms of this model centred on its use of finite reservoirs (buckets) of fossil fuels. Models assuming that resources are finite (i.e., without possibility of substitution or technological change) inevitably predict trouble as the buckets empty. In “The Limits to Growth” world technology and policy can only affect the rates at which the buckets empty. As the models were analyzed, it became clear that modification to include innovation and substitution removed the tendency of the models to predict economic and ecological collapse. [Cole, 1975] summarized this problem as follows:

> *One of [the Limits to Growth model’s] main modes of 'collapse' is resource depletion [caused by] the assumption of fixed economically-available resources, and of diminishing returns in resource technology. Neither of these assumptions is historically valid… That technical change will slow down because of the diminishing opportunities for labour-saving innovations is a highly debatable assumption.*

The controversial results of "The Limits to Growth" attracted enormous attention from the press and the policy community. [McCutcheon, 1979] [Cole, 1975]. Despite its methodological shortcomings, “The Limits to Growth” study brought systems analysis into the energy policy arena. The importance of the study, of its proponents and messages grew 18 months later, in October 1973, when the OAPEC oil embargo triggered the first oil crises. The issues raised by “The Limit to Growth” remain hotly debated during the 1970s to this day.

3.2.1.2 Shell’s Scenarios[5]

Shell has long-standing experience in developing long-term energy scenarios as a tool for better business decision making: its first scenario that dared look out over 50 years was produced in 1995. The educational process engendered by this exercise made Shell managers sensitive to possible surprises, and it allowed the company to respond more readily after the 1973 OAPEC embargo[6].

A group at the Royal Dutch Shell Corporation, under the leadership of Pierre Wack, used scenario analysis as a vehicle for communication within the organization during the sixties. The driving metaphor, the "river of oil," portrayed the company as floating down that river. Scenarios ranged from optimistic (trouble-free continued expansion of production) to pessimistic (political limitation on production, industry restructuring). Optimistic scenarios were portrayed as smooth spots on the metaphorical river, and pessimistic scenarios were described as rapids or waterfalls caused by technical constraints, economic difficulties, or political tensions. The most important prospective tension identified in the scenarios was the growing market power of a few oil-producing nations, especially Saudi Arabia.

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[4] The "Limits to Growth" study was by no means the first in which a model was based on finite resources. In 1865 Jevons wrote a classic study of the energy future of England [Jevons, 1865], stating that “It is true that at best we see dimly into the future, but those who acknowledge their duty to posterity will feel impelled to use their foresight upon what facts and guiding principles we do possess. Though many data are at present wanting or doubtful, our conclusions may be rendered so far probable as to lead to further inquiries…”. Jevons observed that because coal was England's major energy resource, and detailed geological research had characterized its size, England had but two choices: to burn the coal quickly and go out in a blaze of glory or to burn it slowly and eventually become a dying ember. The discovery of oil, along with other technological developments, falsified Jevons' pessimistic view. Nevertheless, the work is an important precursor to modern systems dynamics techniques and is considered so important by the economics community that on its centennial it was reprinted in its entirety.

[5] Although Shell issues its scenarios continuously at regular intervals, hence it should be presented in the following section no. 3.2.3, it is described here because the first Shell scenarios appeared a few months before the first oil crisis. The description is taken from [IEA/OECD, 2003].

[6] The energy scenario analysis approach pioneered at Shell continues to be used successfully by the Global Business Network. For example, a 1990 Global Business Network scenario included a pessimistic forecast emphasizing Middle-East terrorism that seems remarkably prescient today.

In the early 1970s Pierre Wack was able to present Shell's board of directors with two scenarios – one titled "conventional wisdom" and the other titled "oil price crisis scenario". These were made available only months before the October 1973 oil crisis, thus preparing the company for that abrupt change. The company's ability to respond quickly resulted in enhanced profitability – and had the side effect of enshrining scenarios as part of the standard practice at Shell's Group Planning division. Over the years, Shell's planners have been involved in developing scenarios in collaboration with such bodies as the World Business Council for Sustainable Development and the Intergovernmental Panel for Climate Change.

In general the Shell scenarios are of the "exploratory" type, designed around "what if" questions, and written in the form of narratives for greater ease of communication. Quantitative indicators for such variables as energy prices, efficiency levels attained by key technologies, or technology shares in energy supply, are widely employed in the presentations, although the scenarios are not backed by large-scale simulations. Since 1995 the Shell scenarios have considered a time horizon of about 50 years into the future; in contrast, earlier Shell scenarios explored only shorter time frames.

The methodology used at Shell in scenario preparation is a consultative process that largely follows the steps outlined in the section above, and seeks the direct involvement both of the decision makers and of a large multidisciplinary team of experts.

The 1995 Long Term Energy Scenarios were based on the assumption of normal market dynamics but a fast change in the energy system. In both worlds considered by the two scenarios (named Dematerialisation and Sustained Growth) fast technological change fostered by open markets is able to reduce GHG emissions. In the Dematerialisation scenario, energy efficiency improves at a rate equal to the maximum observed historically, and technological advances allow spectacular efficiency gains in areas like vehicles and transport. Renewable energy gains a foothold by expanding in niche markets at first and becoming entirely competitive later, while depletion in some fossil fuels would push up their prices. Nuclear development is hampered by high cost and public acceptance problems. In the Sustained Growth scenario, renewables are characterised by very rapid market penetration, matching the development of oil in the past century, and reaching maximum potential (close to 50% of world primary energy) by 2050.

The latest of Shell's scenarios were released in the fall of 2001. They identify three decisive factors in shaping long-term change: resources, technology and social priorities. The main questions explored by the new scenarios revolve around these factors:

- how long will oil and gas resources be able to meet rising demand and
- what will replace oil in transport;
- what will drive market growth and cost reduction of renewables;
- how will a hydrogen infrastructure develop; and
- what will social and personal priorities be, and how will they affect energy choices.

All these can be summarised by an overarching question: "What energy needs, choices and possibilities will shape a global energy system which halts the rise in human induced carbon dioxide emissions within the next 50 years – leading to a stabilising of atmospheric carbon levels below 550 ppmv – without jeopardising economic development?" [Shell International, 2001].

Before developing scenarios that provide possible answers to the above questions, Shell's analysts considered present trends that are likely to continue into the future. These include the continuing – but changing – link between growth in income and growth in energy demand, or between income growth and attention for the environment; the saturation of certain energy needs, and the fact that, due to improving technology, newly industrialising countries need less energy at the same income level reached in the past by industrial economies.

Another long-term trend, often decisive for the success of a new fuel or technology, is consumers' willingness to pay a premium for superior attributes of an energy carrier/product (convenience, cleanliness, efficiency). This appears to be especially true in industrial countries where consumers seek energy possessing such characteristics as availability on demand, density, safety, cleanliness, portability, ubiquity and unobtrusiveness. Cost and lead-time in energy infrastructure construction, as well as some physical limits to the expansion of fuel/technology market share, are further elements in the list of important but quite predetermined factors.

Similarly, population trends, income growth, market liberalization trends, and energy demand growth are powerful forces in shaping the socioeconomic context for energy, without being fundamental in energy transitions. Demographic trends are fairly well understood and predictable: growth to 8.5 billion people by 2050; ageing population profiles, even in developing countries, and urbanisation of 80% of world population by the end of the period. Slower income growth (3.5% per year as a world average) than in the past century would still push growth in energy demand over the coming 50 years, to probably three times as much as now, but demand saturation would be in sight. Increasing investment in energy efficiency, even with present-day or anticipated technologies, could permit global energy demand growth by 2050 to be only twice as much as today.

Shell's analysis considers that three factors carry much of the uncertainty – and therefore potential for change in the energy system.

Energy resource scarcity, though a rare occurrence at a global level, is one factor that might trigger discontinuities in the system within the next 50 years. Although scarcity is excluded for coal over this time frame, costs of extraction and use might affect its competitiveness. The peaking of oil production is approaching but if unconventional sources are included, scarcity is very unlikely before 2025 and that moment can be pushed another 15 years down the road by vehicle efficiency measures. New supply can still be brought in at costs of less than 20$/bbl for at least the coming decade and the cost of bio fuels should fall below that benchmark within the coming 20 years, constraining oil prices. Even more uncertain is the future availability of gas, for which scarcity could set in from as early as 2025 – to well after 2050. The real issue is timely development of gas transport infrastructure. Nuclear is likely to remain uncompetitive with respect to gas for another two decades, even with emission constraints, but this might change later. Finally, renewable energy resources are potentially plentiful but, especially for wind and solar, development is constrained by lack of appropriate energy storage technology, and cost competitiveness with respect to conventional energy is still not established.

Technology is another area that could bring potentially disruptive surprises. This is especially true in two areas: solar photovoltaics and hydrogen fuel cells. These two technologies, however, display fundamental weaknesses: the first needs significant cost reductions and the acquisition of new forms of storage; the second requires a new fuel transport infrastructure. The uncertainty is whether these two technologies posses sufficiently superior attributes to induce widespread adoption even at premium prices.

Finally, the third key uncertainty is represented by social and personal priorities, particularly attitudes towards energy security or self-sufficiency and attitudes towards the environment. These factors, together with timing, would play differently with respect to any given energy technology or resource and may significantly influence the outcome or the type of solution with respect to climate change.

Around these three axes, Shell analysts built two new scenarios to explore two different paths to a sustainable energy system. A sustainable outcome is consistent with Shell's professed environmental attitudes; it puts a normative character to scenarios that would otherwise be of the exploratory type. While different in focus, both scenarios ultimately converge on a "sustainable" future.

The two scenarios, called Dynamics as Usual and The Spirit of the Coming Age, suggest that by the middle of this century an affordable and sustainable energy system could indeed be emerging. They also show some common traits that should be carefully taken into account in outlining any sensible energy strategy:

- a role of natural gas as a bridge fuel over the next two decades and the importance of security in its supply;
- a strong volatility in oil markets;
- a shift towards distributed or decentralised heat and power supply;
- the potential for renewables and the importance of energy storage technologies (both for power and for hydrogen); and
- the difficulty of identifying winning technologies in periods of high innovation and experimentation.

3.2.1.3 Workshop on Alternative Energy Strategies

In October 1974, one year after the first oil shock, leaders of business, industry, government, and academia from a dozen countries convened the first session of the Workshop on Alternative Energy Strategies (WAES). WAES was an independent organization, with no official ties to any governments or private firms. It was organised into three groups:

1. The Participants were thirty-five senior decision makers from around the world, whose experience in dealing with problems involving the interplay of technology, economics, finance, and government policy made them well-suited to take an active part in the Workshop; they provided or arranged for financial support for WAES activities in their own country and paid for the expenses involved in attending and sponsoring meetings;
2. The Associates chosen by the Participants from their own or cooperating organizations, included scientists, engineers, economists, and managers with expertise in many energy related fields; they conducted the national technical studies and the global integration studies that form the basis for the WAES findings and conclusions; and
3. The Secretariat included the Project Director and a small staff at the Massachusetts Institute of Technology; secretariat expenses were supported by foundation grants. [Wilson, 1977]

The Workshop objectives were to establish a quantitative basis for analysing probable future energy developments through the year 2000 and then identifying feasible alternative global and national energy strategies to deal with these developments. The analyses were designed to provide information that would raise the level of public understanding and assist governments and others in making the choices and formulating the strategies necessary to ensure a proper balance of energy supply and demand during the period 1985 to 2000 and beyond. [WAES, 1976] [WAES, 1977] [Wilson, 1977]

Since no widely accepted methodologies existed of projecting energy supply and demand for periods of ten to twenty-five years into the future, the WAES identified and agreed on the major determinants of future energy supply and demand, to select a range of likely values for these determinants, and to develop an internally consistent and comprehensive framework for synthesising the various national and global studies. Each national team developed detailed econometric projections of the demand and assessed possible national supply contribution at different price levels. Unconstrained integrations were used to identify supply demand unbalances along the years. Constrained integrations, using the Global Energy linear programming (LP) Mini Model (GEMM, Atlantic Richfield Company), linked the cost of closing the gaps to key input assumptions.

The overall findings from WAES analyses centred on the results of integrating supply and demand. When taken together over the period 1972-2000, energy supply and demand developments painted a disconcerting picture of growing shortages of oil. According to WAES resource and production limitations would begin to restrict oil supply in the period 1985-1990 (at 70 Mbbl/d). Further increases in oil demand beyond 1990 would have to be satisfied by other fuels. At the end of the century the demand of above 90 Mbbl/d could not be met within the range of the WAES economic growth, energy price, and national policy assumptions.

Although less debated in the press than “The Limits to Growth”, the 5 WAES scenarios and the methodology had a large impact among the experts. The 13 national reports were the best source of energy related data and econometric analyses for a decade in the respective countries. The econometric analyses at the final energy consumption level gave rise to a set of demand models of the MEDEE type. The LP integration model was the precursor of or contemporary to all the most important LP models, such as DESOM, BESOM and TESOM (BNL), MESSAGE (IIASA), EFOM (EC), MARKAL (IEA/ETSAP).

3.2.1.4 Energy in a Finite World

The Energy Systems Program at the International Institute for Applied Systems Analysis (IIASA) in Laxenburg, Austria, under the leadership of Professor Wolf Hafele, founder and director of the Program and its dominant intellectual and administrative figure since its initiation, carried out a study on “Energy in a

Finite World: A Global Systems Analysis [IIASA/WEC, 1981a/b]. It has been one of the most ambitious and expensive long-term, trans-national energy forecasting efforts, costly and protracted from 1973 to 1981. This broad-ranging study has produced a set of global – the world is split in seven regions – scenario projections to the year 2030.

One of the main statements of the report is not completely dissimilar to main thesis of WAES: “Over the next five decades, even with vigorous conservation measures in industrialized regions, increasing needs for liquid fuels throughout the world may exceed the capabilities of global energy supply systems. The "energy problem," viewed in a sufficiently long-term and global perspective, is not an energy problem, strictly speaking, but an oil problem, or more precisely, a liquid fuels problem.”

The scenarios are the result of a complex methodology. At the centre there is the use of the MESSAGE technical economic optimization model. Its approach is designed to overcome, among others, the difficulty to model the competition of new technologies with existent or other future technologies.

The study attracted enormous attention, primarily due to its degree of elaboration which included sophisticated models and computer work. The attention triggered several polemics, on the method and on the matter. Key examinations of the topic can be found in [Keepin, 1984], [Wynne, 1984], [Thompson, 1984], and [Keepin & Wynne, 1984]. The contributions by Keepin and Wynne raised an important methodological issue: they claimed that the results of scenarios are hard wired to the inputs. [Lovins, 1981] adds: “The IIASA study is of such low technical quality that it is bound, I fear, to be remembered alongside such other pieces of voluminous but inept advocacy as the Rasmussen Report, the Inhaber Report, and Project Independence. The results of the IIASA scenario exercises are not surprising in view of the curious methods they used, as Professor Dennis Meadows pointed out in his review.”

On the matter, the critics of [Lovins, 1981] and the rebuttal of [Häfele, 1981] are representative and quite instructive of the debate on demand projections and supply shares. According to the project head, “in the world of the IIASA High and Low Scenarios, a world that is assumed to be somewhat rational and cooperative, the global average per capita consumption of energy would increase from its current (1980) rate of 2 kW (at about 2.5 kW in 2005) to something on the order of 3 kW (Low Scenario) and 4.5 kW (High Scenario).”[7] “To appreciate the statement fully, one should bear in mind that currently the United States consumes energy at the rate of some 11 kW per capita and most Western European countries at some 5 kW per capita, while the less developed countries use some 0.2 kW per capita of commercial fuels and an additional 0.3 kW per capita of non-commercial fuels.” [Lovins, 1981] states instead that “the United States will live with a per capita energy consumption of less than 1 kilowatt (kW) – and this as a result of the free play of market forces – and that the rest of the world will, of course, do the same.”

On the supply side the controversy is about the contribution of renewable sources and nuclear in 2030. The former would contribute with 7.8% - 10.2 in the High / Low scenario respectively, the latter with 23% in both[8]. The [IIASA/WEC, 1981] scenarios have been labelled as nuclear, not only for their strong arguments in favour of nuclear power plants (including breeders), but also for the asserted need to add to the electric grid a ‘second grid’ for distributing hydrogen (produced by nuclear).

3.2.2 Scenarios for sustainable policies analyses

3.2.2.1 International Project for Sustainable Energy Paths

The International Project for Sustainable Energy Paths (IPSEP) started in California in the late eighties and presented the most comprehensive end-use-scenario analyses. The project was headed by Florentin Krause, formerly at the Energy and Environment Division of the Lawrence Berkeley Laboratory. It was financed,

[7] Multiplied by the assumed population of 7.8 billion people, the low scenario is equivalent to a global consumption of about 17 Btoe in 2030, precisely the same value projected by the IEA/WEO in the 2006 issue [IEA/WEO, 2006].
[8] In the 2002 global energy balance evaluated at the substitution principle, renewable sources contributed with about 17%, nuclear with 5.5%.

among others, by the Dutch Ministry of Environment. Energy systems were analysed in order to show that an efficient and economic climate change mitigation policy was possible. This passed through a cost effective reduction of primal energy supply and final energy consumption without reducing the production of energy services.

The complete reversal of previous scenarios and development patterns was the result of base critics to economic models: they were judged unable to represent the numerous market failures of existing energy markets. Energy systems were analysed from a purely technological perspective and market values projected with a different methodology. The bottom up simulation approach was very detailed. [IPSEP, 1989; 1993; 1994-5] Final energy demand as a whole was first split by sector and each one further split in tens of end-uses. The simulation on a spreadsheet of possible future final energy consumption with the deployment of the most efficient devices showed that the most cost effective combination could reduce considerably the future need for energy supply at a profit.

These type of integrated least-cost implementation of mitigation policies in the United States and EU was later extended from the enlarged energy system to the rest of the economy through the use of input/output economic tables. The extended analysis showed that an integrated no-regrets strategy could reduce export prices for the large majority of industries and limit the impact of climate protection policies on the few most energy-intensive basic materials industries to very small levels. Relative to the baseline, an integrated least-cost implementation of mitigation policies could increase economy-wide employment levels by several hundred thousand jobs in 2010.

These analyses, as many others around the world carried out with similar methodologies, were widely used by the green parties, but disregarded or sharply criticised by traditional market economists. The results of the IPSEP study fit in well with the assessment of the German Enquete Commission (1990, 1995) and German LCP case studies (e.g. LCP case study Hannover, Wuppertal Institute, Öko-Institute 1995).

3.2.2.2 Stockholm Environment Institute - Global Scenario Group[9]

In 1995 the Global Scenario Group at the Stockholm Environment Institute in Boston launched a project, which was to run over several years, on scenarios to explore the problem of transition to sustainability in a global and long-term perspective.

The team of experts and scientists involved in this work recognised the manifold dimensions of globalisation (geo-political, cultural, technologic, economic, biologic, climatic) and the fact that "the world system is at an uncertain branch point from which a wide range of possible futures could unfold in the 21st century" [Gallopin et al., 1997]. Their aim was to explore various scenarios of the future and consider their implications. Since the start of the project, the GSG has developed six scenarios outlined in three major reports.

"The increasingly interdependent global system we observe today is a way station in this sweeping process of growth, transformation and expansion. But a new and ominous feature of the current phase of history is that human impacts on the environment have reached global scales. The contradiction between the growth imperative of the modern world system and the constraints of a finite planet will be resolved. The critical question is, how?" [Gallopin et al., 1997]

This first question the GSG tries to address opens the way to a series of explorative scenarios, describing the range of possible worlds. An additional qualification to this question follows immediately: how can the contradiction between continued growth and the constraints of a finite planet be resolved in a sustainable way? This second question is explored by at least one normative scenario after a discussion and clarification of the sustainability notion.

[9] The description is taken from [IEA/OECD, 2003].

The scenario building process followed by the GSG starts with a characterisation of the current state and of the driving forces, providing a representation of the conditions of the socio-ecological system and the major factors propelling the system forward. Then the scenario description requires the identification of critical uncertainties, the resolution of which will alter the course of events.

The GSG recognises the role of deliberate human actions and choices (influenced by cultural preferences, social visions and psycho-social factors not entirely understood) in shaping the future. As a complement to driving forces, the concept of "attractive and repulsive forces" is introduced [Gallopin et al., 1997]: these are defined as "forces that can substantially redirect beliefs, behaviour, policies and institutions towards some futures and away from others" [Raskin et al. 1996]. As an example of such attractive and repulsive forces the authors include subjective visions of the future, which, operating through human awareness, choice and action become objective forces shaping the evolution of the system.

Finally, these forces shaping the future must include so called "sideswipes": surprises or disasters, such as breakthrough technologies, wars, extreme natural disasters, pandemics or the breakdown of the climate systems.

Another important concept that the GSG considers critical in constructing scenarios is the distinction between slow and fast dynamics operating within the socio-ecological system. The former are typical of high-level structures (governance systems, economic modes of production, cultural preferences, and most environmental processes), while the latter characterise lower subsystem (e.g. responses of individual consumers to price signals). The tension between the slow process of high-level systems and the rapid changes of the subsystems may shape some of the critical uncertainties of the whole. In fact complex systems may become more vulnerable and brittle to the influence of fast change in the subsystems. One such case is the growing persuasiveness and speed of global communications, which accelerate high level processes and generate more potential surprises [Gallopin et al., 1997].

The GSG associates the unsustainability of the current global trajectory with three critical trends, which include: environmental degradation and resource depletion; increasing income disparity; poverty and marginalisation [Raskin et al., 1998]. The drivers that shape the present situation are separated into two categories: "proximate" drivers and "ultimate" drivers:

- Ultimate drivers include: values, desires and aspirations; structure of power; knowledge and understanding; human needs; long-term ecological processes.
- Among proximate drivers the GSG includes: population size and growth; economic volume and patterns; technological choice; governance; environmental quality.

Ultimate drivers are the factors chosen to give the basic characterisation to the GSG scenarios, while the proximate drivers are the ones more easily translated in illustrative parameters.

As mentioned, the GSG develops six scenarios, categorised within a twotiered hierarchy of classes, based on fundamentally different social visions, and variants, reflecting different possible outcome within each class. The scenarios are mostly presented as narratives with the aid of a few indicators; however they are built on an impressive basis of hard data and the scenarios themselves have been quantified using the PoleStar system [Kemp-Benedict et al. 2002].

The three classes are called Conventional Worlds, Barbarisation, and Great Transitions. They are characterised by, respectively, continuity with current pattern, fundamental but undesirable social change, and favourable social transformation.

For each class two variants are defined. Within Conventional Worlds a Reference scenario is developed around mid-range population and economic development projections and using typical technological-change assumptions, while the Policy Reform scenario is characterised by strong, proactive governance in pursuit of sustainability, greater social equity and environmental protection. Both scenarios in this class show a continuity of institutions and values, rapid growth of the world economy and the convergence of world regions towards the patterns set by industrial countries.

The Barbarisation scenarios outline a future of deterioration of the social, economic and moral structures of civilisation as markets and policy reforms become incapable of coping with emerging problems. Its Breakdown variant features uncontrollable conflict, institutional disintegration and economic collapse. The Fortress world scenario is characterised by an authoritarian response to the threat of breakdown, by which the rich elite tries to protect itself and its privileges by controlling and repressing an impoverished majority.

The Great Transition scenarios examine visionary solutions to the problem of sustainability, through fundamental changes in values and in socioeconomic arrangements. In these scenarios population levels are stabilised at moderate levels and materials flows through the economy are dramatically lowered as a result of lower consumerism and use of environmentally friendly technologies. The Eco-communalism scenario represents a regionalist and localistic vision characterised by small-is-beautiful and autarkic concepts. The New Sustainability Paradigm scenario shares some of these goals but tries to build a more humane and equitable global civilisation rather than retreat into localism.

Figure 2 offers a quick reference, for the six scenarios, of the behaviour over time of six descriptive variables: population growth, economic scale, environmental quality, socio-economic equity, technological change and degree of social and geopolitical conflict.

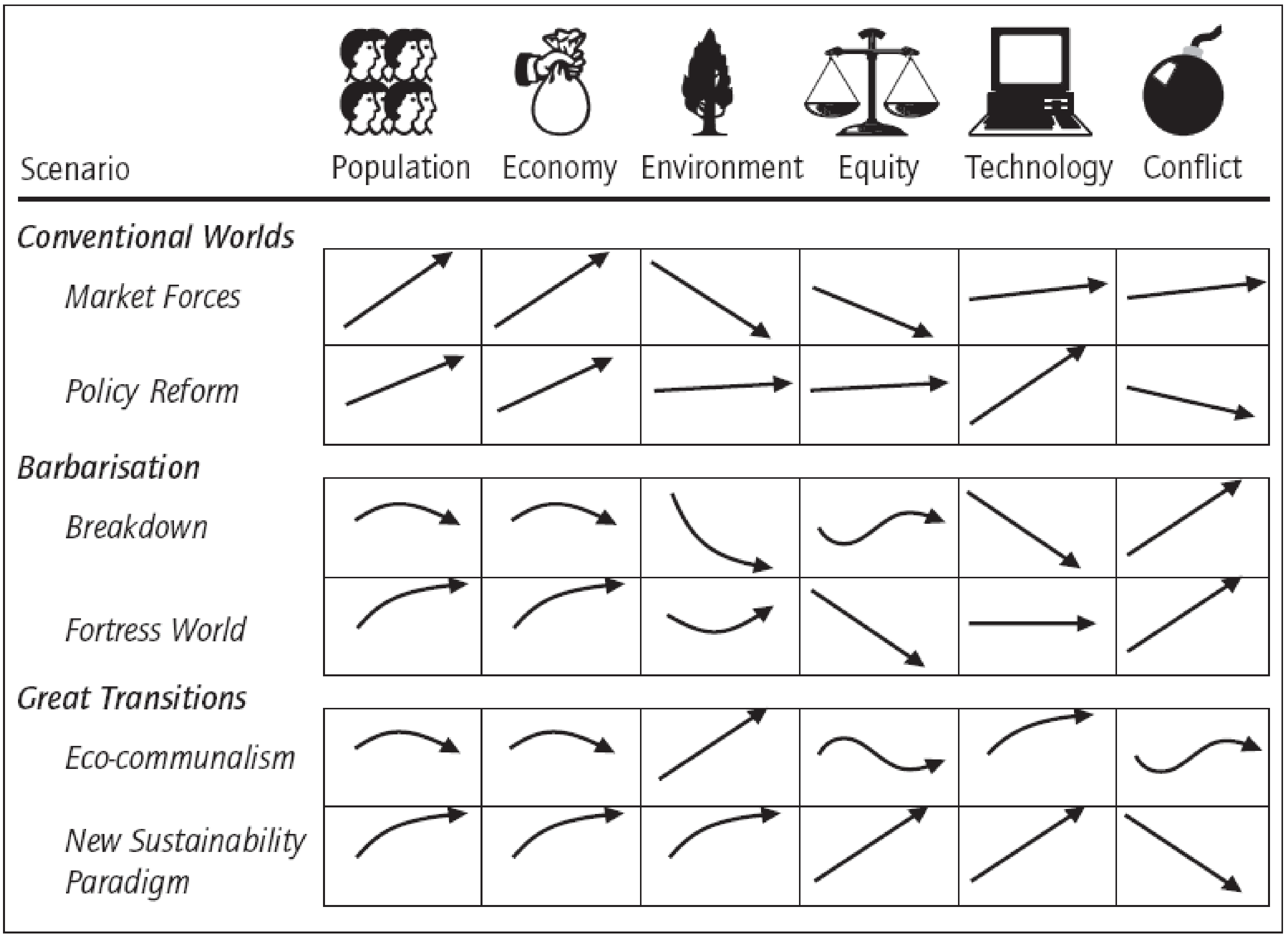

Figure 2: Summary Table of GSG Scenarios and Trends in Some Key Variables

3.2.2.3 Millennium Project[10]

The Millennium Project of the American Council for the United Nations University (ACUNU) is "a global participatory futures research think-tank of futurists, scholars, business planners, and policy makers who work for international organizations, governments, corporations, NGOs and universities". The project is carried out in partnership with the Smithsonian Institution, and The Futures Group International. It collects, assesses and manages judgements and analysis about the future and its global challenges from its network of several hundred participants: this information is used to produce annual "State of the Future" reports. As a part of a project started in 1996 a series of global exploratory scenarios looking out to 2050 were developed.

The process of developing the scenarios, after a thorough literature survey, started with a questionnaire sent via e-mail to a certain number of correspondents. The questionnaire presented a list of 18 fundamental drivers or dimensions that could be used to span the scenarios, and asked participants to indicate the four most important. The list included such elements as communications technology (from vibrant to stagnant), degree of globalisation (from free trade to isolationism), pollution (from disastrous to being cured), population growth (from high to low), and so on. [ACUNU, 1998]. Among the 35 responses to the questionnaire, the four highest-ranking drivers or dimensions were:

- degree of globalisation (from free trade to isolationism);
- communications technology (from vibrant to stagnant);
- threats to global security and or quality of life (high to low); and
- government participation in society (high involvement to little, or laissez faire).

Permutations of the extremes of these axes were used to form 16 possible scenarios. However, not all 16 scenarios were developed: only four were considered worthy as the most interesting for further developments as exploratory scenarios, while two more where selected for development into possible normative scenarios [ACUNU, 1998].

A characteristic matrix was constructed to provide the essential outline of the four explorative scenarios' content. The purpose was to guide the team in preparing the initial narrative drafts. The matrix listed important elements in such domains as: demographics and human resources; environment and biodiversity; technology; governance and conflict; international economics and wealth; and integration. Then from previous work a checklist of issues (e.g. widening income inequality, increasing scarcity of fresh water, and so on) was drawn up and the most important of them (based on collective judgement by the team) elaborated in each scenario. This was done by trying to imagine what would be the consequences of those developments or issues in each of the worlds described. The same was done with a list of promising developments (e.g. diffusion of biotechnologies or new vaccines, acceleration of trends towards democracy) [ACUNU, 1998].

The next step was quantification through the use of models. At the beginning of the project, an informal enquiry was conducted among selected global modellers, about models and their potential uses in scenarios. Questions asked were: What models would you consider for this application? Specific scenarios and generalised models don't match. Is it then necessary to build specialised models to quantify a specialised scenario? How can we effectively link specialised scenarios into more general global models? Do you know of any global models that are based on adaptive-agent modelling or on chaos/complexity principles?

Responses to these questions showed that in the history of global model use in scenarios, early global models produced scenarios based on their projections – and there were no global models or studies in which the scenarios came first and produced the assumptions required for the model. When models are used this way, assumptions must be made about exogenous variables (such as population growth rate or productivity) (ACUNU, 1998). Choosing these exogenous variables always involves judgement on the part of the modeller, and values are often based on an implicit scenario:

Implicit scenario ➡ Exogenous assumptions ➡ Modelling ➡ Scenario construction based on model runs.

[10] The description is taken from [IEA/OECD, 2003].

Other respondents indicated that a high degree of quantification does not necessarily equate to accuracy, and that no matter what the model, simplicity was a desirable characteristic. Some recommended the use of modelling approaches that depend on judgements – heuristic modelling – rather than historical statistics for their relationships. A few recommended presenting outputs of futures studies in the form of dynamic, interactive computer programs adapted to the needs of decision-makers. Most stressed the danger that a policymaker, when presented with a scenario in quantified form, may confuse precision with accuracy, while what is in fact needed is to render uncertainty more explicit [ACUNU, 1998].

For these reasons the Millennium project decided to use models to help assure consistency, but having the scenario drive the model rather than vice-versa. In this perspective, the explicit scenarios illustrated earlier, were used to provide the backdrop for the choice of the values for the exogenous variables in the selected model. Therefore, when the model was run, its output was consistent with the scenario on which the exogenous variables were based and the model provided quantitative estimates of the value of variables that were incorporated in the scenario. Hence:

Lookout panel developments + Scenario axes ➡ Scenario construction ➡ Exogenous assumptions ➡

Modelling ➡ Scenario quantification (based on model runs)

The model International Futures (IF), made available by Barry Hughes of the University of Denver, was selected based on its user-friendliness. In order to run the model, a matrix was produced in which the columns consisted of exogenous parameters (or "handles") in the IF model, and the rows of specific scenario features. The team members entered judgements into the cells of this matrix, depicting the effect (in terms of increase or decrease) of the scenario features on the variables of the IF model. However, there were many anticipated effects that the model could not handle, either for lack of parameters or due to its structure [ACUNU, 1998].

This procedure was carried out for each of the scenarios to assign values to each of the scenario-dependent variables: in some cases the values were given elements of the scenarios, while in others they were judgmental and selected to be consistent with the spirit of the scenario. Finally, the explorative scenarios and the model outputs were sent to a selected group of experienced scenario writers and political experts for comments and revision.

A comparison across these scenarios, carried out through scenario quantification, shows that by 2050 world population is highest in the Passive Mean World scenario and lowest in Cybertopia, world GDP is highest in Cybertopia although Trading places has highest growth between 2020 and 2040. CO2 concentrations are highest in Cybertopia and lowest in Mean worlds and atmospheric temperature follows the same pattern. World literacy is highest in Trading places and lowest in Mean world [ACUNU, 1998].

Concerning the normative scenarios, the process followed for their construction required the identification of four primary norms from a list of 15 goals circulated among a panel of experts. The four most important were 1) environmental sustainability; 2) plenty (all people have basic necessities of life); 3) global ethics (identified and accepted); and 4) peace. These norms were meant to form the core of the normative scenario, while the body of the scenario was composed of the actions to address the stated global challenges. After a first draft of the scenario, a panel of long-term normative-oriented experts reviewed it and improved it [ACUNU, 1999].

The Normative World in 2050 is a world that has finally achieved an environmentally sustainable global economy, capable of providing nearly all people with basic necessities and a majority of them with a comfortable living. The resulting social stability produced relative peace giving leisure to people to look ahead for the second half of the 21st century. Three different specifications were developed for this scenario depending on what were thought to be the main forces capable of bringing about such a future. The three forces were: a) breakthroughs in science and technology; b) development of the human potential; and c) political and economic policies [ACUNU, 1999].

3.2.2.4 World Business Council for Sustainable Development[11]

In 1997 the World Business Council for Sustainable Development (WBCSD) launched on behalf of its partner companies an effort to formulate a set of global scenarios to explore possible responses to the challenge of sustainable development. In particular the underlying question was how businesses can respond to these challenges [WBCSD, 1997]. No less than 34 multinational corporations participated in this project, which was led by a core team of experts from WBCSD, Shell International and the Global Business Network. The resulting global scenarios were intended to provide a framework for focused industry or corporate scenarios.

The process of scenario building was conducted with the following approach. At first, trends that emerged in the last 50 years were described and the major global threats to the environment and its viability were identified. These include: loss of crop- and grazing land; depletion of tropical forests; extinction of biological species; rapid population growth; shortage of freshwater resources; over-fishing, habitat destruction and pollution of the marine environment; threats to human health; climate change related to GHG concentrations in the atmosphere; acid rain and air pollution; pressure on energy resources. Among the solutions to these problems is development of technology. However, diffusion of new technology is a time- consuming process and our ability to absorb it depends less on its availability than on our appreciation of its importance, which slows our capability of taking action against environmental threats. Another key element in the concept of sustainable development is the idea of economic prosperity for present and future generations and of social equity for all, without which misery, war and social conflict can result on a planetary scale.

From this analysis two key elements of uncertainty emerge, around which the scenarios are developed:

- what are the critical environmental thresholds and how resilient is the global ecosystem?
- what human social systems can best respond to the challenge of sustainable development?

Three key driving forces are identified which can be considered as "predetermined" elements that will certainly persist into the future and shape all scenarios:

1. social and technological innovations, new economic and social actors;
2. population increase; and
3. increasing interdependence and interconnectedness, thanks to new communication technologies that increase the speed of knowledge transfer, but unfortunately do not yet raise the speed of problem solution, due to the growing complexity of governance.

Around these questions and factors three scenarios are developed: the FROG (first raise our growth) scenario; the GEOpolity scenario; and the Jazz scenario. These scenarios explore the two questions above but develop around different possible human responses to the challenge of sustainable development, in other words, around the values and beliefs (or myths) held by the individuals. Elements of plausibility are abundant: most of their underlying trends can be found to be operating at present. Yet it is virtually certain that none of them will be entirely true: real life is going to be a mix of them, but understanding how some of those trends might actually develop and work is certainly a good way to prepare for them.

3.2.3 Institutional scenarios issued regularly[12]

3.2.3.1 International Institute for Applied Systems Analyses and World Energy Council

The World Energy Council (WEC) is a non governmental organization, assembling since 1930 major oil & gas and electric suppliers worldwide. Since 1934 it produces a Survey of Energy Resources. Its 20th issue [WEC, 2004] reported resources and consumption worldwide for all main energy sources: coal (including lignite), crude oil and natural gas liquids, oil shale, natural bitumen and extra-heavy oil, natural gas, uranium and nuclear, hydropower, peat, wood fuels and other bio-energy, solar geothermal wind tidal wave and ocean

[11] The description is taken from [IEA/OECD, 2003].
[12] Scenarios issued regularly, year after year, become more important because energy analysts tend to use the same source in their related analyses.

thermal energy. The WEC survey portrays an evaluation of future availability of energy resources – so technically speaking it is a scenario although the name does not officially appear – that influences most energy scenarios prepared by other groups.

The International Institute for Applied Systems Analyses (IIASA) has always been active in studying possible developments of the global energy system. Given that:

- global energy needs are expanding with economic development around the world and population growth,
- there is strong evidence that growing energy use risks damaging the environment and changing global climate, and
- consumers want higher levels of more efficient, cleaner, and less obtrusive energy services,

IIASA studies how much of those needs will be met by fossil fuels, how much by alternative fuels, and how much by efficiency increases and expanded energy conservation.

In 1998, as a result of a five year study, IIASA and the World Energy Council (WEC) present six alternative long-term energy futures. The study was conducted in two phases. The first, from 1993 to 1995, developed the six scenarios for 11 world regions and analyzed their implications. The results were presented in [IIASA/WEC, 1995]. The second phase, from 1995 to 1998, was devoted to an extensive review of the study assumptions, results, and implications for the 11 world regions. Teams of regional experts and reviewers, totalling over 100 individuals, were convened to provide more thorough regional assessments and alternative perspectives. The final results, incorporating the regional reviews plus an updated, expanded, and more detailed presentation of the six scenarios than in 1995, are presented in [Nakicenovic et al., 1998].

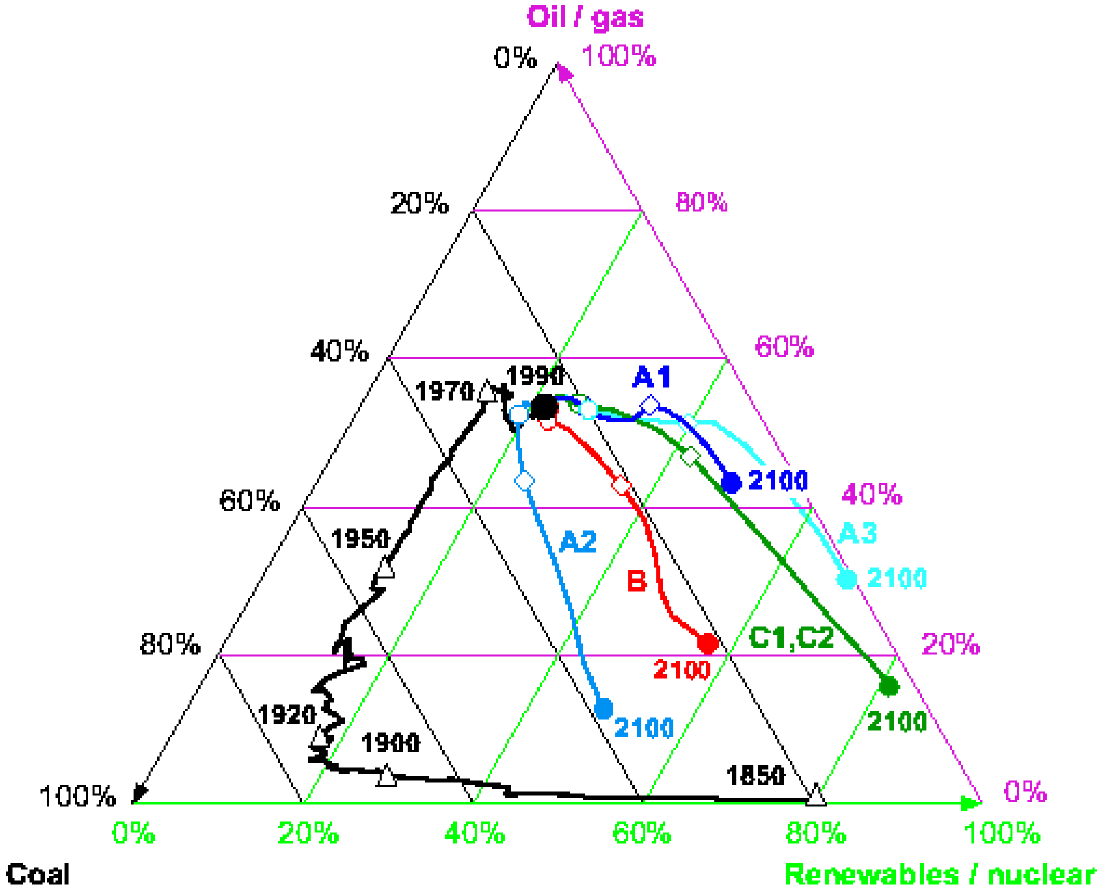

Figure 3: Evolution of the global primary energy structure in the IIASA-WEC scenarios (1850-2100)

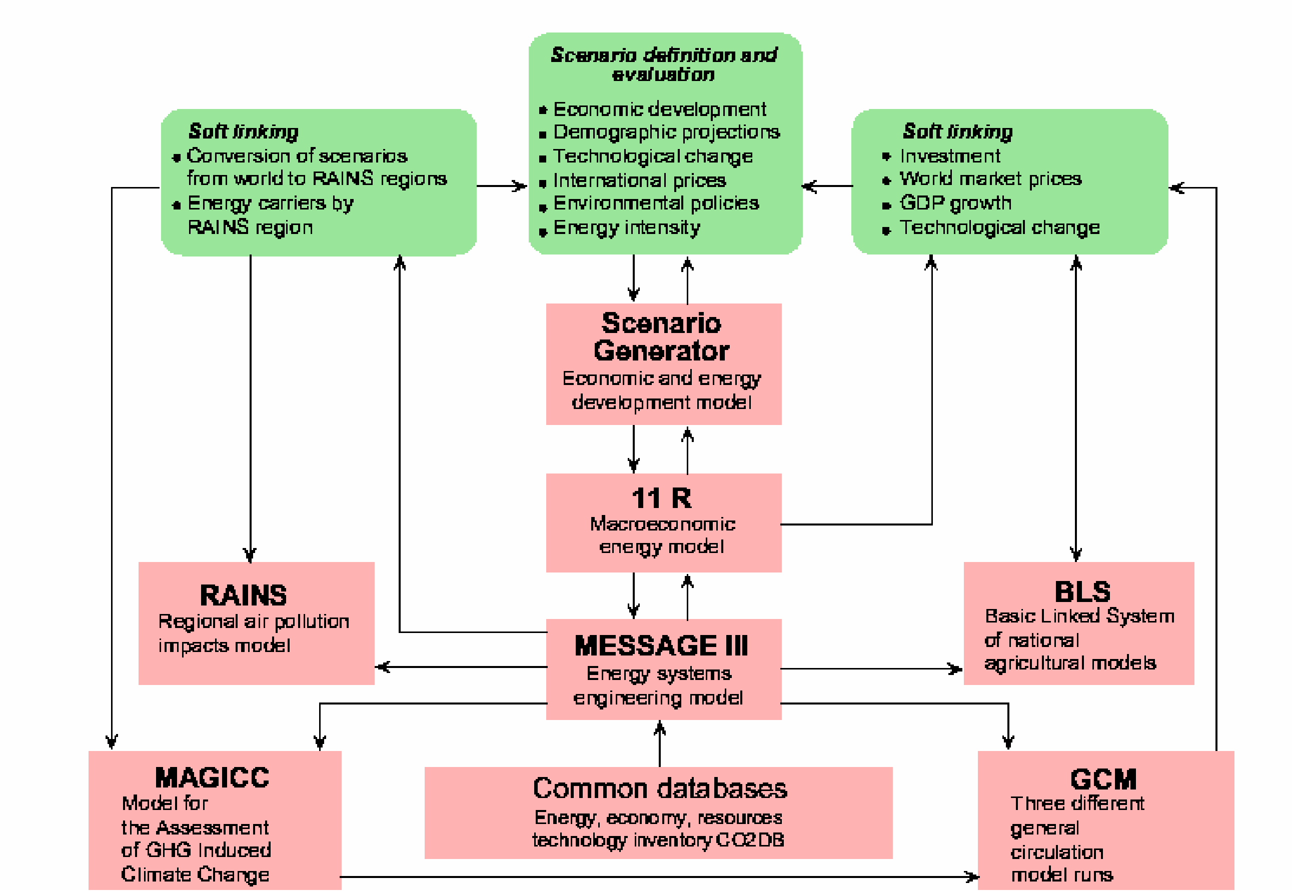

Figure 4: The methodology used for building the IIASA-WEC scenarios

The six scenarios cover a wide range -- from a tremendous expansion of coal production to strict limits, from a phase-out of nuclear energy to a substantial increase, from carbon emissions in 2100 that are only one-third of today's levels to increases by more than a factor of three (see Figure 3). All allow significant economic growth without exhausting energy resources, but all require substantial, yet different, early investments. These early investments will determine which fuels, technologies, efficiency gains, conservation patterns, and pollution levels are most likely to characterize the 21st century.

An online database (at: http://www.iiasa.ac.at/cgi-bin/ecs/book_dyn/bookcnt.py) makes available input and output of the study. The objective was to examine more thoroughly the period beyond 2020, where the real potential for change lies. To that end the study integrates near-term strategies through 2020 with long-term opportunities to 2050 and beyond; analyzes alternative futures with a unified methodological framework using formal models and databases to ensure consistency and reproducibility; incorporates a dynamic treatment of technological change; harmonizes regional aspirations with global possibilities. The flows diagram in Figure 4 outlines the methodology.

3.2.3.2 International Energy Outlook

The Energy Information Administration, which depends from the US Parliament, issues yearly an International Energy Outlook (IEO), twin to the more known Annual Energy Outlook (AEO) for the US based upon the use of NEMS. The report assesses the outlook for international energy markets in the following 20-25 years. Together with the reference scenario, a high economic growth and a low economic growth case are developed, which consider alternative growth paths for regional GDP [EIA/IEO, 2006].

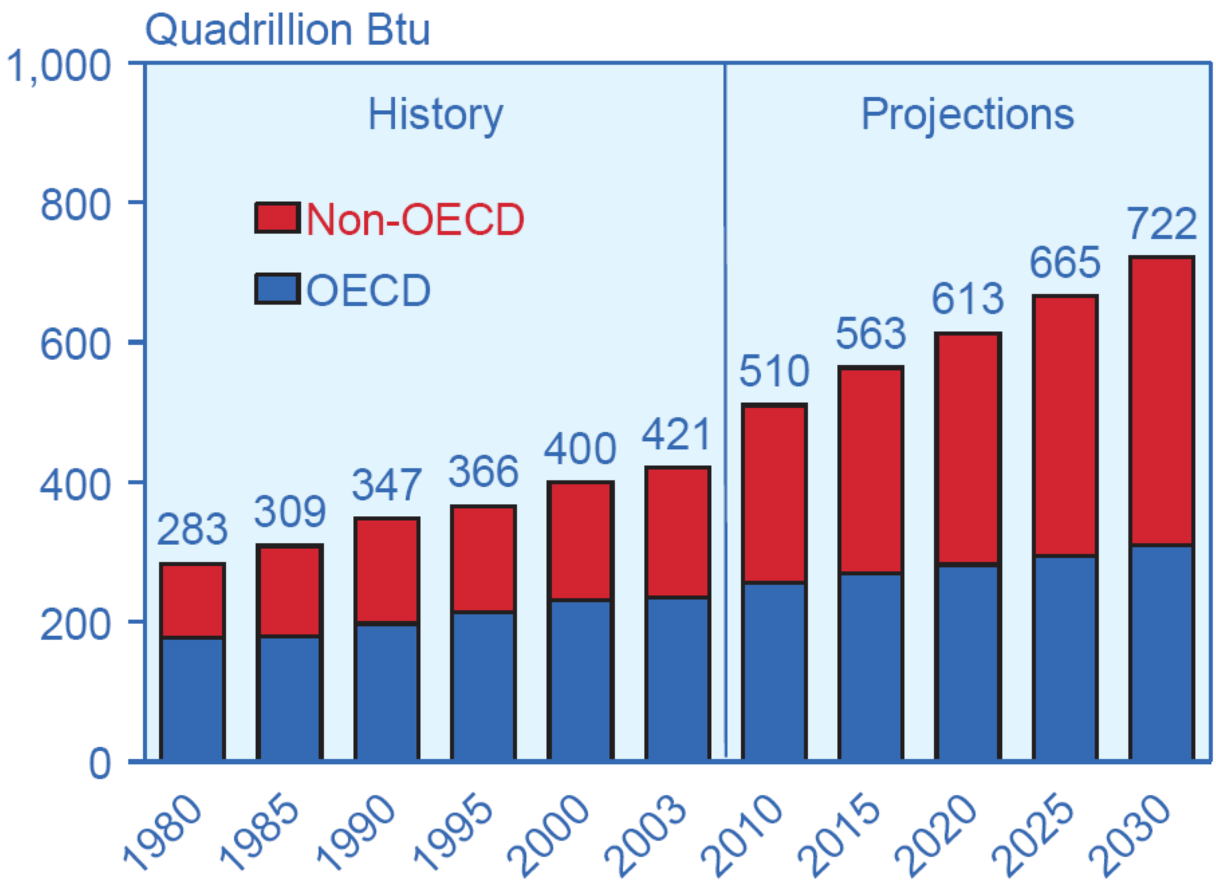

Figure 5: World Marketed Energy Consumption by Region, 1980-2030 [US-EIA/IEO, 2006]

The projections of world energy consumption appearing in the most recent issues of IEO are based on the System for the Analysis of Global Energy markets (SAGE), a modelling tool derived from MARKAL. SAGE calculates world projections for 15 separate regions/nations. For each region, reference case estimates of 42 end-use energy service demands are developed on the bases of demographic and economic projections. Projections of energy consumption to meet the energy demands are estimated on the basis of each region's existing energy use pattern, the existing stock of energy using equipment, and the characteristics of available new technologies, as well as new sources of primary energy supply. Contrary to standard MARKAL models, SAGE is myopic and investment decisions are taken in each period without knowing the potential long term benefits of for instance earlier introduction of more expensive more efficient technologies. Therefore the investment decisions that bring the equilibrium in one year are fixed and carried over in the following year as an existing stock.

The most recent issues, although the projections are compiled with the new technology explicit methodology of SAGE, continue the traditional approach, supply oriented and favouring comparatively high energy consumption (see Figure 5). The strength of the report is the rich historical energy data base, including the US Geological Survey of World Energy Resources, and the solid and well documented methodology.

3.2.3.3 World Energy Outlook

Since the early eighties, the Economic Analysis Division of the International Energy Agency (IEA, an independent branch of the Organization for Economic Cooperation and Development, OECD, Paris) issues the World Energy Outlook every two years. Most of the report is centred in a Reference Scenario, where demand and supply are analysed in a 30 years time horizon (see Figure 6). The first part analyses the prospects of oil, coal, natural gas and electric markets separately. The second part gives details of some particular region or country, changing along the years. The third part describes a possible Alternative Policy Scenario. Analysts make wide use of the hundred and more pages of simplified energy balances tables, with projections by fuel, region, time horizon, and scenarios.

Since 1993, the World Energy Model (WEM) has been the central tool for the compilation of world energy scenarios. The WEM is a mathematical model made up of five main modules: final energy demand, power generation, refinery and other transformation, fossil fuel supply and CO2 emissions. The development and running of the WEM requires access to huge quantities of historical data on economics and energy variables. Most of the data are obtained from the IEA's own databases of energy and economic statistics. A significant amount of additional data from a wide range of external sources is also used. The parameters of the demand-side modules' equations are estimated econometrically, usually using data from 1971. To take into account expected changes in structure, policy or technology, adjustments to these parameters are sometimes made over the scenario period. Cross-country analyses or expert judgement are used when shorter time series or unstable situations hinder econometric estimations.

On top of copies distributed by the secretariat to governmental representatives in various IEA committees, the WEO sells over a thousand copies. Due to the fact that the IEA is an international organization, mostly independent from the national instances, WEO regional, and in some case national, energy projections are used by several government and institutions in preparing domestic reports, analyses and pre-regulation assessment.

In the most recent years the main message of WEO seems that the world energy system is not sustainable in the 30 year time horizon, not much in terms of energy resources, but in terms of CO2 emissions and investments. Compared to other scenarios, the WEO shows high value; in this sense it may be considered a supply oriented view. By its very methodology, it focuses on energy goods markets; it mainly projects the past history with a methodology partly similar to WAES.

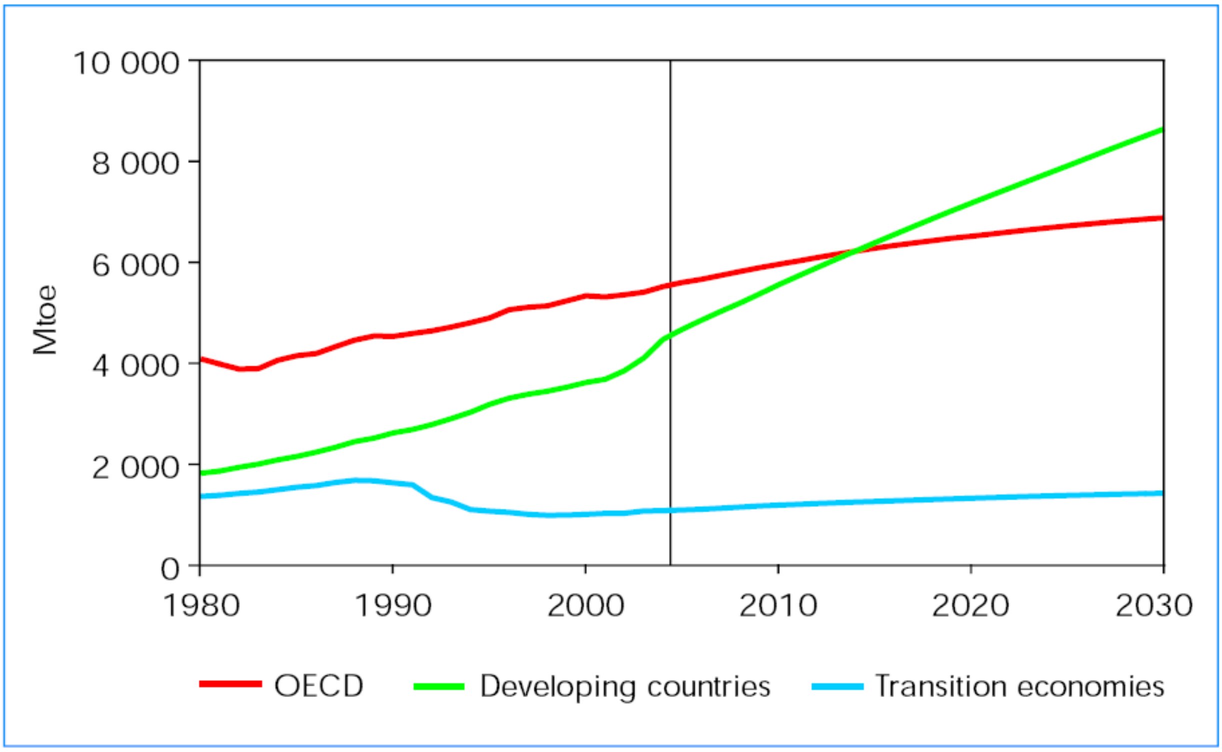

Figure 6: World Primary Energy Demand by Region in the Reference Scenario [WEO, 2004]

The 2006 edition depicts two scenarios, the Reference Scenario and the Alternative Policy Scenario, which describe two different futures with respect to whether new policy measures are introduced or not. The Reference Scenario serves as a baseline, but not a preferable or even a likely scenario, and the Alternative Policy Scenario as an explorative scenario, with a variety of different policy measures that might be adopted due to economic or environmental reasons. The same macroeconomic and population assumptions are used in the Reference and Alternative Policy scenarios. A policy and measure database of over 1400 policies aimed at energy security and climatic concerns were divided on the basis of whether the policies were already been adopted or not. The Reference Scenario carries on the policies already under implementation, whereas the Alternative Policy Scenario assumes that all of the policies are eventually adopted.

3.2.3.4 Energy Technology Perspectives

Reacting to this 'fatalistic' point of view, pushed by the G8 leaders and the head of China, India, Brazil, Mexico and South Africa, who signed the Gleneagles Communiqué in 2005, in 2006 the Office of Energy Technology and R&D of the IEA has started issuing the "Energy Technology Perspective: Scenarios and Strategies to 2050", with the firm intention to update it every two years. As the WEO, the ETP is published under the authority of the IEA Executive Director, and does not necessarily reflect the views of the IEA member countries. As stated in the title, the report focuses on technologies: in part 1 it evaluates their potential impacts in future energy market developments, in part 2 it gives a photograph of present technologies, their research, possible breakthroughs and markets by sector: plants, transport, industry, residential and commercial.

The ETP shows several scenarios showing possible outcomes of more effective policies for the development and deployment of new energy technologies. The core tool of the analysis is a 15 region global technical economic model of the MARKAL family. The enormous technological detail allows presenting results on technologies as well as market (see Figure 7 and Figure 8).

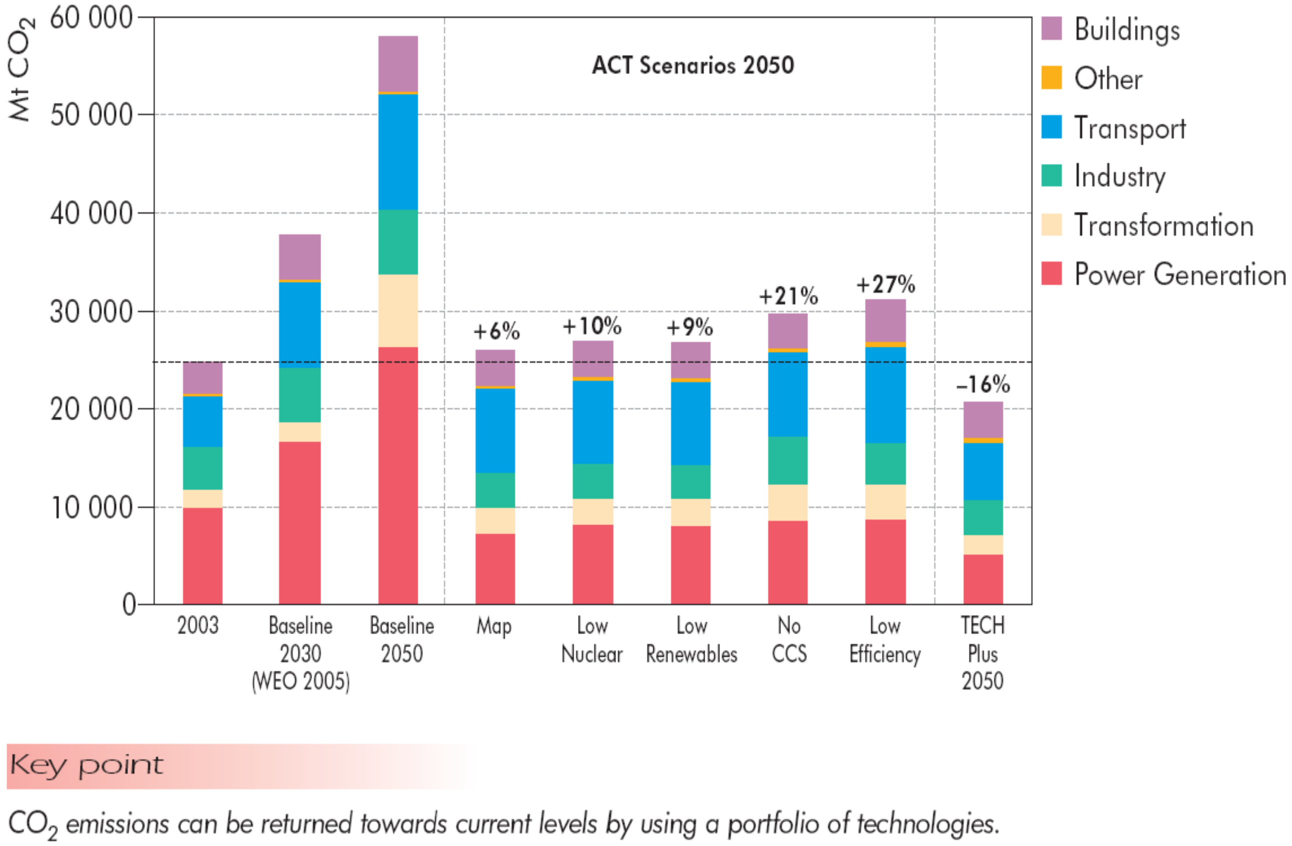

Figure 7: Global CO2 emissions by scenario [IEA/ETP, 2006]

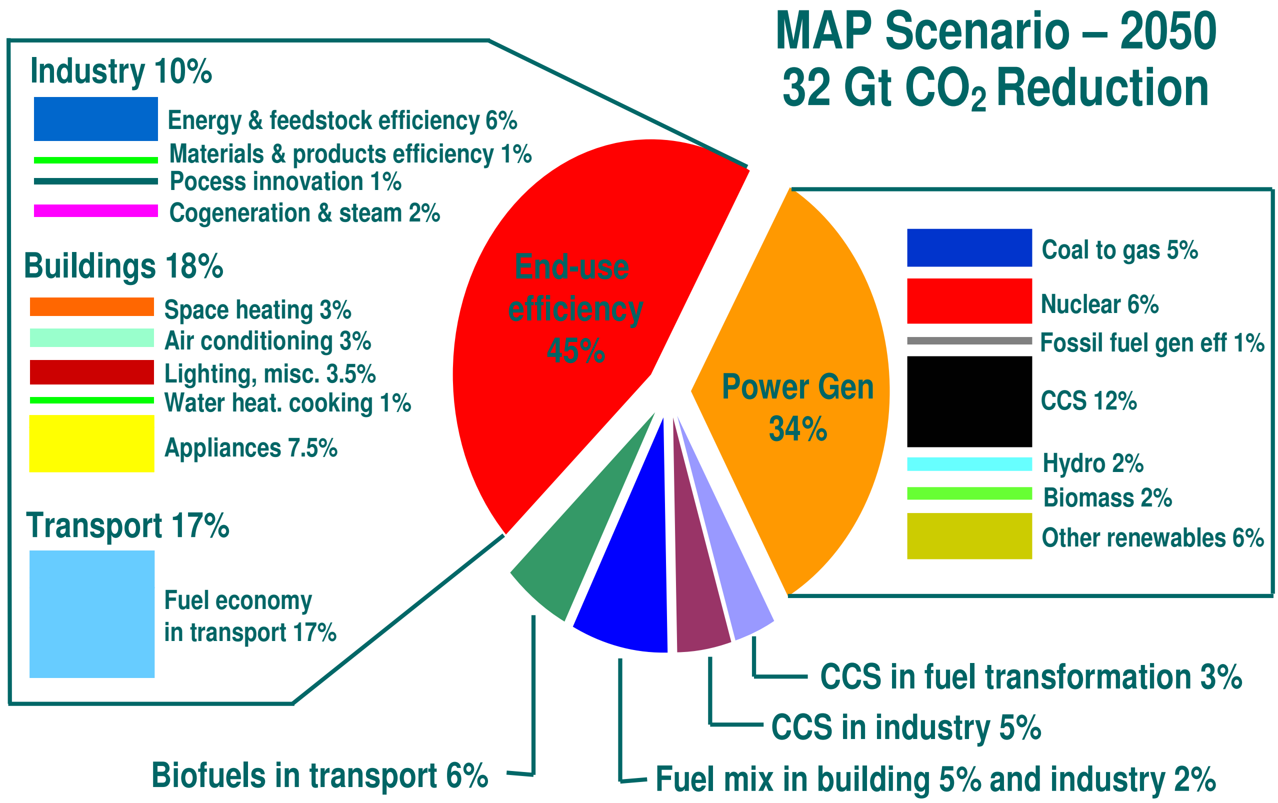

Figure 8: CO2 emission reduction: technology action vs. baseline scenario [IEA/ETP, 2006]

Since the past is not embodied in the form of econometric correlations but as the stock of capital in energy plants and end use devices at the start year, the tool enable the analyses of long term systems quite different from the present one.

The impact of the ETP report is still to be evaluated. So far is has been well accepted by the highest policy levels and the sectors involved in energy RD&D. However its diffusion has been lower than WEO.

3.2.3.5 ITPS POLES model[13]

The Institute of Prospective Technological Studies (IPTS) of the EU Joint Reseach Centre, located in Sevilla, develops and maintains the POLES model for energy policy analysis (http://energy.jrc.es). The POLES model is a world simulation model for the energy sector. It works in a year-by-year recursive simulation and partial equilibrium framework, with endogenous international energy prices and lagged adjustments of supply and demand by world region.

Developed under EC research programs at the Institute of Energy Policy and Economics (IEPE) and currently also operated, expanded and maintained by the IPTS[14], the model is fully operational since 1997. It has been used for policy analyses by EC-DGs Research, Environment, and Transport and Energy, and by the French Ministry of Environment.

[13] The illustration of POLES, as well as some info on WEO and SRES models, is taken from [VTT, 2007]
[14] IPTS is developing a series of modules for energy intensive industries (iron & steel, cement, aluminium, refineries & petrochemicals, and pulp and paper) as well as a detailed transportation model to be integrated in the POLES model.

POLES contains 18 world regions and 32 countries. The model enables to produce detailed long-term (2030 / 2050) world energy outlooks with demand, supply and price projections by main region. It produces CO2 emission marginal abatement cost curves by region, and emission trading systems analyses under different market configurations and trading rules. In addition, the model can be used to analyse technology improvement scenarios, with exogenous or endogenous technological change and the value of technological progress in the context of CO2 abatement policies.

3.3 The Scenarios of the Intergovernmental Panel on Climate Change[15]

The Intergovernmental Panel for Climate Changes has periodically prepared long-term global scenarios focusing on emissions of greenhouse gases that can be used for the purpose of assessing climate change, its impacts, as well as adaptation and mitigation options. The IPCC has produced such scenarios in 1990, 1992, 1994 (a re-evaluation of 1992 scenarios), and then a Special Report on Emissions Scenarios in 2000. The 1992 scenarios (known as the IS92) were the first to provide estimates for the full set of greenhouse gases; these estimates were in turn used to drive global circulation models to develop climate change scenarios.

In 1996 the IPCC decided to develop a new set of scenarios, taking into account input and perspectives from a wide, interdisciplinary research community in an innovative "open process", which allowed consideration of different social, economic and technological factors and their impacts on emission trends (see Table 2 above). The scenarios, exploring a temporal horizon that extends to 2100, do not include future policies explicitly to mitigate climate change and specifically do not assume implementation of the UNFCCC or of the emissions targets of the Kyoto Protocol.

The process involved:

- an extensive review of the existing scenario literature;
- the analysis of the main scenario characteristics, their different driving forces and their relationships;
- the formulation of four main storylines as narrative description of as many alternative futures;
- the quantification of the storylines through the use of a wide array of models and modelling approaches;
- the review of the resulting emissions scenarios and of their assumptions through an open consultation process; and
- repeated revisions, following this review process, of the scenarios and of the Special Report before its release in 2000.

As a result of the early stages of the analysis, the team of IPCC experts identified as the main drivers of future greenhouse gas trajectories factors like demographic trends, social and economic development and the rate and direction of technological change. Energy demand levels and land use patterns are directly influenced by these factors.

Based on the results of the literature review and on new data, population projections were revised downwards with respect to the 1992 scenarios. Furthermore all scenarios are characterised by growing per-capita incomes, as a result of gross world product increases of 10- to 26-fold depending on the case; income differences across world regions are assumed to narrow down in many of the scenarios described. Technology is considered a key driver at the same level as population change and economic growth: in fact the same assumptions on income and population dynamics can lead to greatly divergent paths in terms of energy demand and environmental impacts depending on the technology or energy resource assumptions used. These different assumptions in the SRES scenarios span a wide range of energy structures and systems. Finally land use patterns and related assumptions (particularly those related to trends in global forest areas) are of significant importance in these scenarios: although in most of cases forest areas are assumed to decrease for the first decades, ultimately a reversal of this trend is projected [IPCC-SRES, 2000].

[15] The description is taken from [IEA/OECD, 2003].

Four storylines were elaborated. Besides excluding consideration of climate change policies, these scenarios also excluded outlying (i.e. extreme with respect to the literature) "surprise" or "disaster" scenarios. Each of the storylines represents a combination of different demographic, social, economic, technological and environmental developments, and describes consistently the relationships among those drivers without expressing judgements or preferences for one scenario versus the others. Within those four main storylines a wider set (or family) of quantified scenarios is developed using a broader range of values for the main driving forces identified as well as different modelling approaches: most of the models represent integrated assessment frameworks. The resulting set of 40 quantified scenarios covers a wide range of uncertainties on future GHG emissions deriving from:

- Uncertainties in the parameters expressing the driving forces (demographic, social, economic and technological ones). It is interesting to note that 13 of these scenarios are devoted to the exploration of differences stemming from different energy technology assumptions.
- Differences in models' characteristics and structure.

It is important to note that no probability of occurrence is assigned a priori to these scenarios.

The four storylines, from which originate four scenario families, assume distinctly different directions for future developments and end up diverging in increasingly irreversible ways: together they encompass a significant portion of the uncertainties implicit in the main driving forces identified. The four storylines or scenario families are called respectively A1, A2, B1 and B2 [IPCC-SRES, 2000]. Within the A1 family three scenario groups are identified, characterising three different developments of energy technologies: A1FI is fossil fuel intensive and includes six scenarios simulated by different models, A1T describes a predominantly non-fossil fuel case (simulated with three models), and A1B is a balanced case (eight simulations with different models). The families A2, B1 and B2 have six, nine and, respectively eight scenarios (see Figure 9).

Within each scenario family two different types of scenarios were developed: scenarios with harmonised assumptions about economic growth, population trends and final energy use (there are 26 of them) and scenarios with alternative qualifications of the storyline (14 scenarios) to explore additional uncertainties. Marker scenarios are, for each storyline, the scenarios that best illustrate that storyline.

The work was done with six modelling approaches (included in table 2):

1. Asian Pacific Integrated Model (AIM): a large scale climate change simulation model for Asian-Pacific region that couples both top-down and bottom-up approaches; linked to a global model in order to produce global estimates. The National Institute of Environmental Studies, Japan.
2. Atmospheric Stabilization Framework Model (ASF): using regional population and economic drivers forms demand for energy which is matched with the supply through a market model; agricultural and deforestation emissions are projected through estimates for the production of major agricultural products.
3. Integrated Model to Assess the Greenhouse Effect (IMAGE): a set of three integrated models for energy and industry, terrestrial environment and ocean-atmospheric interaction; the energy system dynamics are bottom-up modeled with investment decisions in generation and efficiency and supply based on anticipated demand, costs and institutional delays.
4. Multiregional Approach for Resource and Industry Allocation (MARIA): a compact regional integrated assessment model using constant elasticity of substitution production functions; energy market prices are endogenously generated from extraction and utilization costs, and demand levels are estimated for industry, transportation, and other public uses.
5. Model for Energy Supply Strategy Alternatives and their General Environmental Impact (MESSAGE): a part of an integrated modelling framework; exogenous population and economic projections are used to produce estimates for energy supply, which are fed to top-down (MACRO) and bottom-up (MESSAGE) optimization models with resource availability and technology palettes as constraints; non-energy emissions are taken from the AIM model 2ICF Consulting.
6. Mini Climate Assessment Model (MiniCAM): a small rapidly running integrated assessment model for GHG emissions and climate change effects; energy sector emissions are calculated using labour force levels and labour productivity with a GNP/energy elasticity in a partial equilibrium model.

Based on the above assumptions and storylines, the SRES scenarios span almost the entire range of carbon dioxide, other GHG and sulphur emissions found in the current scenario literature. Furthermore the six scenario groups cover a rather wide and often overlapping range of emissions, which fan out the farther we go into the projected future. It is important to note that similar GHG emissions trajectories can be produced by very different socioeconomic developments and, conversely, similar developments of the driving forces considered may result in different future emissions: it is the uncertainty in the future development of key factors that may cause large swings in future emissions, and which is responsible for the overlapping of projected emission ranges [IPCC-SRES, 2000].

The range of cumulative emissions from all sources as quantified by the SRES scenarios through the year 2100 goes from 770 Giga-tonnes of carbon to 2540 GtC. The lower bound is approximately the same as the one estimated for the IS92 scenarios, while the upper bound is higher than the maximum range reached by the IS92 scenario (estimated at 2140 GtC). Cumulative emissions are a key element in governing any stabilisation of concentration, more so than the pattern of change of emissions from now until the time of stabilisation [IPCC-SRES, 2000]. As shown by , some of the SRES scenarios show trend reversals, turning points as well as crossovers (i.e. cases in which initially emissions are higher in one scenario but later emissions are higher in another one). In most cases of trend reversals, the increasing emissions trend due to income growth, is more than compensated for by productivity improvements combined with slower population growth (or even decline) [IPCC-SRES, 2000].

Box SPM-1: The Main Characteristics of the Four SRES Storylines and Scenario Families.

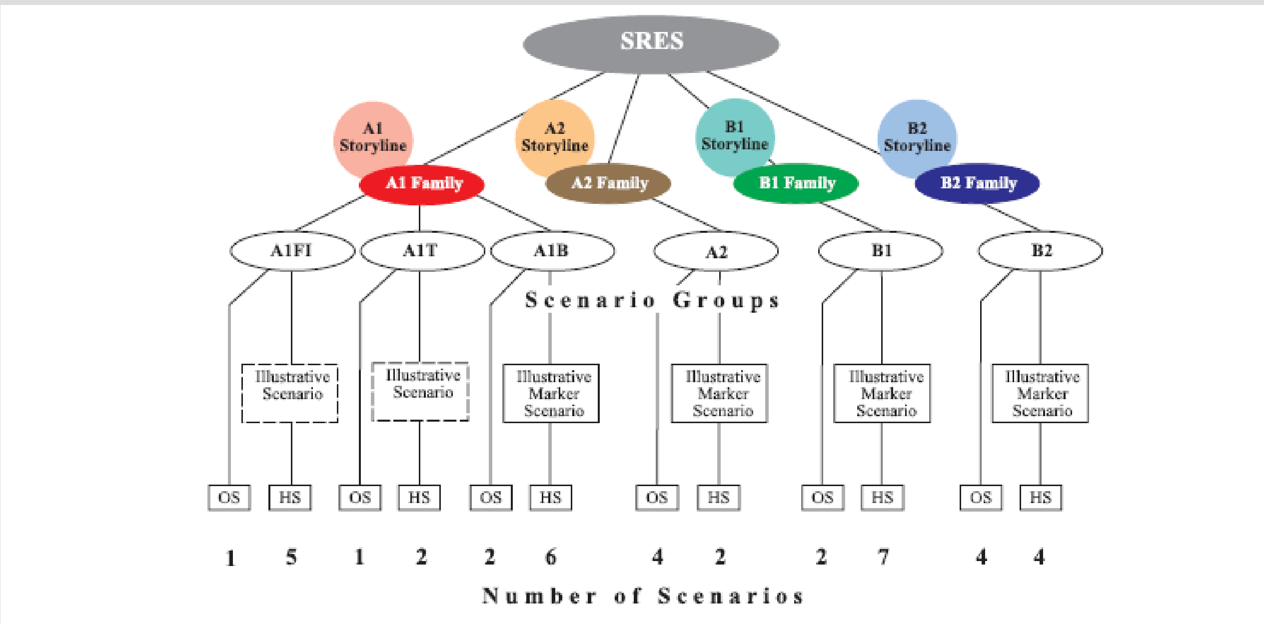

Figure SPM-1: Schematic illustration of SRES scenarios. Four qualitative storylines yield four sets of scenarios called "families": A1, A2, B1, and B2. Altogether 40 SRES scenarios have been developed by six modeling teams. All are equally valid with no assigned probabilities of occurrence. The set of scenarios consists of six scenario groups drawn from the four families: one group each in A2, B1, B2, and three groups within the A1 family, characterizing alternative developments of energy technologies: A1FI (fossil fuel intensive), A1B (balanced), and A1T (predominantly non-fossil fuel). Within each family and group of scenarios, some share "harmonized" assumptions on global population, gross world product, and final energy. These are marked as "HS" for harmonized scenarios. "OS" denotes scenarios that explore uncertainties in driving forces beyond those of the harmonized scenarios. The number of scenarios developed within each category is shown. For each of the six scenario groups an illustrative scenario (which is always harmonized) is provided. Four illustrative marker scenarios, one for each scenario family, were used in draft form in the 1998 SRES open process and are included in revised form in this report. Two additional illustrative scenarios for the groups A1FI and A1T are also provided and complete a set of six that illustrate all scenario groups. All are equally sound.

Figure 9: Storylines and Scenario Families of the [IPCC-SRES, 2000]

3.4 *Annex A: Fusion in past energy scenarios: a review*[16]

If fusion is mentioned at all in energy scenario publications, then it is not included in scenarios for themselves but only in accompanying comments. All fusion-related sections in the analyzed publications are categorized along topics such as research, feasibility, research funding, unlimitedness and comparison with fast breeders.

a) Research: WEC (1993): There should be scientific and technical research for the long term (post 2020) into climate change, fast-breeder reactors, fusion, new renewable energy resources, and new technologies for the production and use of electricity.
b) Feasibility: IIASA/WEC (1981b): "More needs to be said here about fusion. So far its development has been aimed at achieving scientific feasibility - that is, producing more energy by fusion than is consumed by the fusion devices. This is now expected fairly soon (CONAES 1978)". Nakicenovic et al. (1993) state that "the feasibility has to be demonstrated".
c) Research funding: Dessus (1996)."Cette même année (author's note: 1990), les crédits pour la seule fusion nucléaire représentaient plus de deux fois l'ensemble des crédits accordés à la maîtrise de l'énergie (énergies renouvelables comprises)" - in the year 1990 the fundings for nuclear fusion alone were more than two times higher than the whole fundings that were granted for achieving control over energy problems (including renewable energies).
d) Unlimitedness: IIASA/WEC (1981b): "We also note that the resource situations of the two breeders (author's note: fusion and fission) is comparable. In both cases, the easily available resources are equivalent to a few hundred thousand terawatt-years, so that for all practical purposes, each of the breeders permit an unlimited supply of energy." "In the more distant future the fusion reactor will go a step further, in order to allow a fusion of deuterium with deuterium. Under these circumstances, the energy resources would be further enhanced by a factor of 1000; energy supply would then be even more unlimited."
e) Comparison with Fast Breeders: For the Fusion Programme Evaluation Board (Barabaschi S. et al. 1997) fusion "neither precludes nor competes directly with the development of other energy systems". Energy scenario authors – such as IIASA/WEC (1981b, 1995) - are of a different opinion. For them fusion is not isolated from fission. Both will compete with each other for the same market niche. IIASA/WEC (1981b): "Our discussion of the nuclear option did not touch on fusion except peripherally. It does not seem to be a major factor within the period of our study, even if technical and economic problems were solved. The market dynamics would be too slow. Fusion might, however, contribute to the breeding of nuclear fuel as might the technology of "accelerator breeding". Current prospects for these technologies do not seem to us to be particularly favourable, although it is too early to judge their value." IIASA/WEC (1995): "In all cases, energy options that are not technically feasible today are excluded. Nuclear fusion, for example, is excluded, while hydrogen is included as an energy carrier, because it can be produced with current technologies, although not yet at competitive costs..." "We have not included nuclear fusion explicitly in the study. Had this been done, fusion would have assumed or shared the role played by breeder reactors. However as different the two may be from an engineering point of view, there is little to distinguish them in the scenarios. Both are large, centralized, carbon-free, producers of electric power that generate radioactive waste and have a practically infinite resource base. In our attempt to treat future technologies as generically as possible, therefore, breeding and fusion reactors, viewed through today's binoculars, look very much alike." Surprisingly there is nearly no difference in the perception of fusion between these studies, although there are fourteen years in between the dates of publication. This means that about one and a half decades of fusion research between the early 1980s and today were unable to change the expectations of future energy researchers. Häfele (1990) noted that, although fusion has "not yet passed the threshold of scientific feasibility and cannot be incorporated into future scenarios, it holds great promise".

In a 'surprise in scenario' Shell International Petroleum Company (1995) expects that "By 2060, sources of supply are likely to be more diversified than today". "A second wave, possibly including magma energy and/or a surprise15, might take-off by 2050." One of these "surprises" could, of course, be fusion. The most unconventional scenarios are the so-called "Surprise-Rich" scenarios published in Anderberg (1989). Although these would have been a suitable occasion to include fusion for example in a "Big Shift to Fusion" scenario, fusion's place in the mind of the authors was not sufficient for getting this attention. One part of the SERF programme was to bring additional fusion vectors into existing scenarios. However, this attempt originated from the "fusion community" and has not yet spread into the "energy scene".

[16] Text and table reproduced from [Gazso, Kromp, 2001].

Table 4: Overview of fusion in other relevant publications

Publication:	Year	Code	Publication:	Year	Code	Publication:	Year	Code
Amagai	1991	0	Häfele	1990	2	Marshall	1980	0
Barbaschi	1996	10	Häfele	1980	5	Marchetti	1993	8
Bodanski	1996	2/4	Häfele and Lauppe	1991	0	Marchetti	1989	8
Chandler et. al.	1998	0	Hammond	1972	4/10	Nakicenovic	1997	8
Chandler et al.	1990	0	Hammond et al.	1973	10	Nakicenovic et al.	1997	2
Davis	1990	0	Hirsch et al.	1997	9	Report to US Congress	1989	4
Edmonds et al.	1986	0	Holdren	1991	2/4	Reddy and Goldemberg	1990	0
European Commission	1995	1	Holdren	1990	7	Reddy et al.	1991	0
European Commission	1996	0	Holdren and Pachauri	1992	0	Sassin	1980	0
European Commission	1997	0	Huang	1993	0	Sassin et al.	1997	0
European Parliament	1997	2	Jackson	1991	0	Schrattenholzer	1998	0
European Parliament	1995	3	Johansson et al.	1996	0	Sinyak and Nagano	1994	0
Frisch et al.	1989	0	Lawrence Livermore	1996	4	Starr	1993	0
Goldemberg et. al.	1985	0	Lin Gan	1990	0	Velikov and Kintner	1980	4
Gouni	1990	2	Logan et al.	1990	7	Williams and Feiveson	1990	0

Codes: 0 not mentioned; 1 there should be research; 2 feasibility; 3 compared R&D fundings; 4 unlimitedness; 5 role compared with fast breeder; 6 surprise; 7 reducing safety, waste and proliferation hazards; 8 hypothetical SOLFUS; 9 tokamaks/ITER not useful for the development of practical fusion power; 10 included.

Some studies deal with the time frame of fusion technology. For Edmonds and Reilly (1985), for example, ”Fusion energy is dismissed as a contributor to energy supplies in the base case because it is, as yet, technologically unproven. While gains in fusion technology are being made it is unlikely that a commercial fusion industry could be developed to a level that would have a major impact on energy supplies by 2050”. Gouni (1990) states: ”Fusion must be placed in the context of the energy scene over the next half century or one hundred years...”. One further publication that is of special importance in this regard is the logistic substitution model by Marchetti and Nakicenovic (1979), see also Marchetti (1993). It consists of a phenomenological approach to analyze past market penetration processes and derive general laws that may be applicable to future processes. Marchetti and Nakicenovic predicted a negligible role over the next 50 years for new energy technology sources such as geo-thermal energy, solar energy and fusion because of the very long lead times intrinsic to the system. The authors also included a SOLFUS curve, which stands for SOLar or FUSion. This particular scenario - qualified as ”completely hypothetical” by the authors - assumes that fusion will start in the year 2000 and will reach a 1 % market share by 2002. It further assumes a penetration rate equal to coal oil and gas. The time constant (time to go from 1 to 50 percent of the market share) for the introduction of a new energy source in the world is about 100 years. Keeping these speed assumptions in mind and taking into account that the first commercial fusion reactor is now expected to enter the stage around 2050, it would take about another 50 years until a (primary energy) market share of 10% is reached (the share of the electricity market will of course be higher). The above scenario requires assumptions, such as: fusion will be economically competitive right from the start, no unexpected problems emerge, and this development is not distorted by government intervention, e.g. subsidies. Accordingly, fusion can reach a dominant market share in the 22nd century at the earliest.

In conclusion, the clear majority of the cited energy scenario publications do not mention fusion, although some include general statements about fusion. All of them are convinced that fusion is not a viable option to solve problems that society considers to be vital in the future, such as greenhouse gas emissions and global warming. Furthermore, they agree that fusion will not play a major role in the first half of the 21st century.

4 Methods

4.1 The problem: predictions vs. scenarios

When the year comes for which energy scenarios have built projections, it is easy to verify that there is always a gap with actual events and statistical measurements. Nobody is surprised. The fact that we can calculate the calendar for as many as desired future years does not mean that those years exist per se, and even less that we have knowledge about the events taking place in those years. Strictly speaking the future exists only in people expectations, base upon human history and personal experience. In this same sense, every predicate about the future is conditional.

The content of expectations about the future highly depends on the subject and the event. If the course of the space-time is not changed by unexpected cosmic events, such as the absorption of the milky way by a black hole or the impact of an extraterrestrial body, in 2100 we expect a total solar eclipse on September 4, between 9.10 am and 9.25 am in a central zone of Madagascar, but we cannot say how much different the country will be from the present republic of 18.6 million people, an average Gross Domestic Product of less that 300 US$2005 per capita, an average consumption of 0.05 toe/capita and 45 kWh/capita. This is because by experience and rationality we expect that the laws of astronomy will continue holding as well as personal freedom. In fact, if the course of events we are used to by history or personal experience is not changed by unexpected events, such as the disappearance of any personal freedom of thoughts or action, we cannot predict today how many people will be living on earth tomorrow or the day after, not to say in hundred years.

The misunderstanding about projecting to 2100 the global energy system is rooted in the fact that it is a complex fabric of socio-technical sub-systems. In the frame of our present scientific and technical knowledge of nature, we cannot project that out of the same amount of crude oil we will be able in 2100 to extract amounts of heat or movement above the thresholds fixed by the laws of mechanics and thermodynamics (second section of Table 5 and Table 6). They have been well established by experiments and rationality, therefore we assume they will hold for as long as nature exists. On the contrary, in the frame of the same knowledge of nature, we cannot say how much heat or movement will be demanded in 2100, because we cannot say now whether it will be demanded by 20 billion people or 2 billion people (and say 10 billion robots), nor how much heat and movement will which one demand[17] (third and last section of Table 5 and Table 6).

The same misunderstanding holds in the field of energy related pollutions and climate changes. The science of climate is rapidly growing, as well as the reliability of climate laws[18]. But temperatures and other climate changes in 2100 cannot be predicted because we cannot predict the inputs to climate laws, i.e. the amount of anthropogenic greenhouse gases (GHG) emitted from now to 2100, because they are related to unpredictable personal freedoms and behaviours.

That is why in projecting energy systems experts are confronted with both uncertainty and ignorance. Uncertainty is related to possible development of the technical parts of the system. Ignorance is related to the intrinsically non deterministic aspects of the systems and derives from the impossibility of predicting the outcomes of personal freedom and social behaviours.

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[17] In fact the theory does not exclude the possibility to know here and now something about a different specific point in space-time, including future times, due to some perturbations of the space-time []. Furthermore there is (little and sparse) experimental evidence of people knowing in the present point of space-time something about another specific point in space-time, including future times []. However neither the theoretical nor the experimental evidence permits extrapolations from point specific events.

[18] In my opinion, the scientific literature is incorrect in design climate laws as “climate models”. The fact that climate laws are quantitatively expressed by thousands of complex equations instead of a few as for astronomy, does not mean that they are not laws of nature, dictated by rationality and experimental evidence. And the uncertainty gap surrounding climate laws is reducing at much faster pace than astronomical laws in the past.

Table 5: Global summary energy balance for 1973 [IEA, 2004]

1973 (in Mtoe)	Coal	Crude oil	Oil Prod.	Nat. Gas	Nuc.	Hydro	Bio.	Elec.*, Other	TOTAL
Indigenous Prod.	1476	2936	-	994	52	319	673	9	6459
Imports	140	1577	410	73	-	-	0	8	2209
Exports	-130	-1611	-441	-73	-	-	0	-8	-2264
Stock Changes	12	-22	-16	-15	-	-	0	-	-41
TPES	1498	2880	-47	980	52	319	673	9	6363
Intl. Marine Bunkers	-	-	-119	-	-	-	-	-	-119
Transfers	-	-43	49	-	-	-	-	-	5
Statistical Diff.	0	12	-7	5	-	-	-	0	9
Electricity Plants	-557	-23	-318	-159	-52	-319	-3	499	-932
CHP Plants	-88	-	-28	-51	0	-	-1	101	-67
Heat Plants	-9	-	-1	-1	-	-	-1	7	-5
Gas Works	-9	-1	-9	14	-	-	-	-	-5
Pet. Refineries	-	-2800	2773	-	-	-	-	-	-28
Coal Transf.	-169	1	-3	0	-	-	0	-	-171
Liquefaction Plants	-2	0	-	-	-	-	-	-	-1
Other Transf.	-	4	-5	0	-	-	-11	-	-13
Own Use	-34	-3	-162	-107	-	-	0	-58	-364
Distribution Losses	-7	-7	0	-8	-	-	-	-43	-65
TFC***	622	21	2121	672	-	-	657	516	4608
Industry Sector	358	16	556	381	-	-	99+	277	1686
Transport Sector	33	-	905	18	-	-	-	10	966
Other Sectors	226	-	528	273	-	-	559+	228	1814
Non-Energy Use	5	4	132	-	-	-		-	141

+ split assumed by the editor
*: Other includes: solar, wind, geothermal in the primary section, electricity and heat in the use section.
+ The Total Final Consumption is equal to the original IEA data; the Total Primary Energy Supply is not, because here all non-fossil electricity has been converted to primary equivalent by using the same average fossil efficiency of 38.79%. When the physical energy principle is used, as in the original IEA energy balances, nuclear weighs three times more than hydro when the output electricity is the same.

Confronted with the scientific impossibility of predicting long term future developments of complex socio-technical systems, such as the global energy systems, and the practical need of restricting the field of possible future events or anticipating something about the future for improving present decision and better cost benefit analyses of present investments, scenario building is the best compromise that experts have found so far. The following assumptions underlie every scenario building exercise:

- The present logic (rational thinking) is extrapolated without changes;
- The quantitative laws of physics, chemistry and related natural sciences hold unchanged; and
- The laws of social sciences (economy, communication, etc.) don't change significantly within the time horizon of the scenario.

Once these principles are assumed, it is possible to verify whether a scenario portrays an internally and externally consistent and coherent view of possible futures. For instance, a scenario has to balance the demand with some supply, since energy / mass cannot be created. Similarly, verbal / written communication will not be overtaken by mental communication procedures. Also the laws of equilibrium, that regulated so far any economic development, supposedly will not change in the time horizon under analysis.

Table 6: Global summary energy balance for 2002 [IEA, 2004]

2002 (+), in Mtoe	Coal	Crude oil	Oil Prod.	Nat. Gas	Nuc.	Hydro	Bio.	Elec.*, Other	TOTAL
Indigenous Production.	240	3647	-	2169	591	577	1118	68	10573
Imports	447	2072	740	584	-	-	1	45	3889
Exports	-436	-1947	-813	-583	-	-	-2	-44	-3824
Stock Changes	-12	-2	16	3	-	-	0	-	6
Total Primary Energy Supply	2402	3770	-56	2173	591	577	1118	69	10643
Intl. Marine Bunkers	-	-	-146	-	-	-	-	-	-146
Transfers	-	-104	119	-	-	-	-	-	15
Statistical Diff.	-21	-14	8	-5	-	-	0	0	-31
Electricity Plants	-1404	-28	-212	-447	-578	-577	-31	1172	-2105
CHP Plants	-178	-1	-30	-258	-13	-	-32	282	-229
Heat Plants	-62	-1	-17	-86	-	-	-9	148	-28
Gas Works	-11	-	-4	8	-	-	-	-	-7
Pet. Refineries	-	-3642	3618	-	-	-	0	-	-24
Coal Transformation	-155	0	-3	0	-	-	-	-	-158
Liquefaction Plants	-18	11	0	-8	-	-	-	-	-14
Other Transformations	0	30	-28	-4	-	-	-44	-	-45
Own Use	-45	-9	-207	-201	-	-	-2	-143	-606
Distribution Losses	-2	-3	0	-21	-	-	-	-145	-171
Total Final Consumption	505	11	3043	1153	-	-	1000	1384	7095
Industry Sector	382	11	603	515	-	-	160	572	2242
Transport Sector	5	0	1746	57	-	-	8	20	1837
Other Sectors	106	0	504	580		-	832	792	2814
Non-Energy Use	12	-	190	-		-	-	-	201

*: Other includes: solar, wind, geothermal in the primary section, electricity and heat in the use section.
+ The Total Final Consumption (TFC) is equal to the original IEA data, but not the Total Primary Energy Supply (TPES). Here non-fossil electricity has been converted to primary equivalent by using the same average fossil efficiency of 38.79%. When the physical energy principle is used, as in the original IEA energy balances, nuclear weighs three times more than hydro, although their electric outputs are nearly the same.

Within this consistency framework, the region in the space of possible / plausible events is established by the scenario experts, and it is partly subjective. The range of possibilities or degrees of freedom for scenario building is clearly represented by Figure 10, where the range is represented in the scale of times. It is necessary to look at the future and its uncertainties in an articulated fashion, beyond the simple assumption that present trends will continue tomorrow. Over time horizons of five to ten years the inertia of the energy/economy system is so strong as to leave little room for change, but over longer periods the future will almost certainly look different.

With reference to Figure 11, the plane x.y represents the space of events. The point B represents a scenario; by definition it is inside the feasibility region. Scenario studies normally describe also the path from the present (point A) to the projected scenario (point B). By definition, the likelihood of scenario B, as well as of other points in the feasibility region, is subjective. If we now add to Figure 11 the z-axis to represent probabilities, a surface represents the likelihood of each possible scenario.

The rest of this chapter deals with methods for building consistent views of the future. Questions about the function and the practical use of scenarios are dealt with in the next chapter.

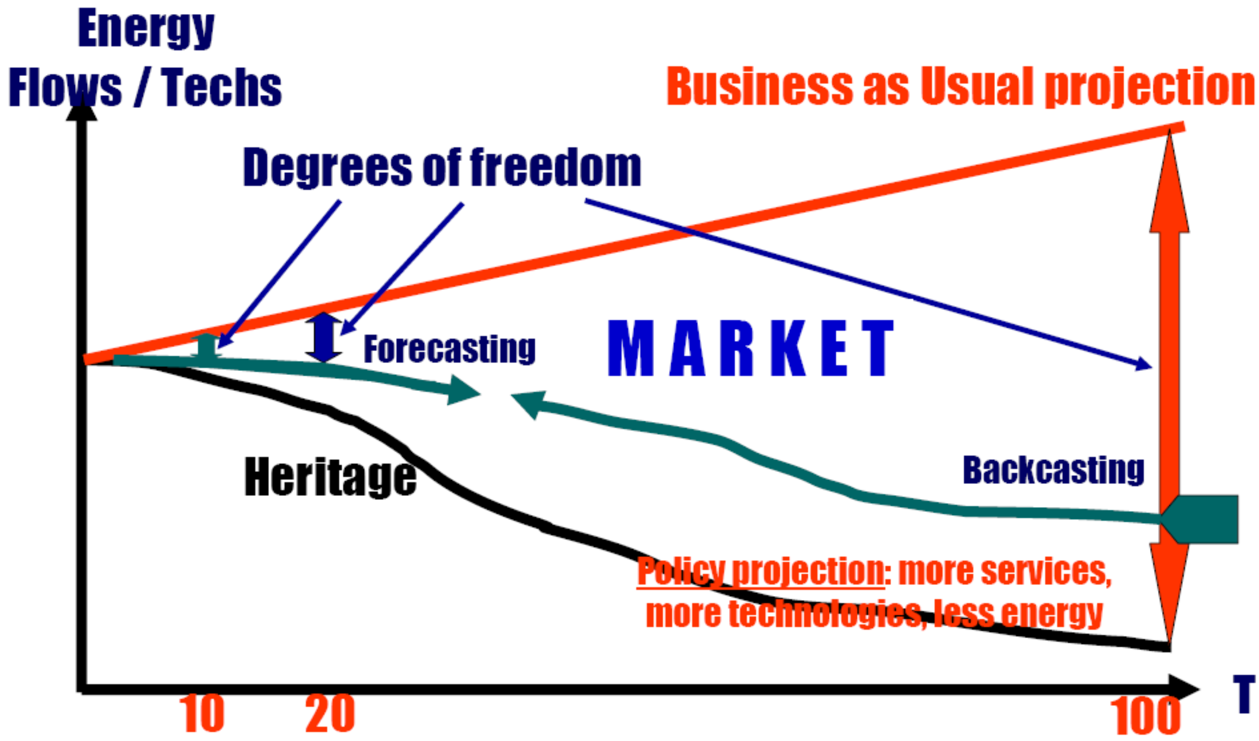

Figure 10: Feasibility region for scenario building [Chateau, 2005]

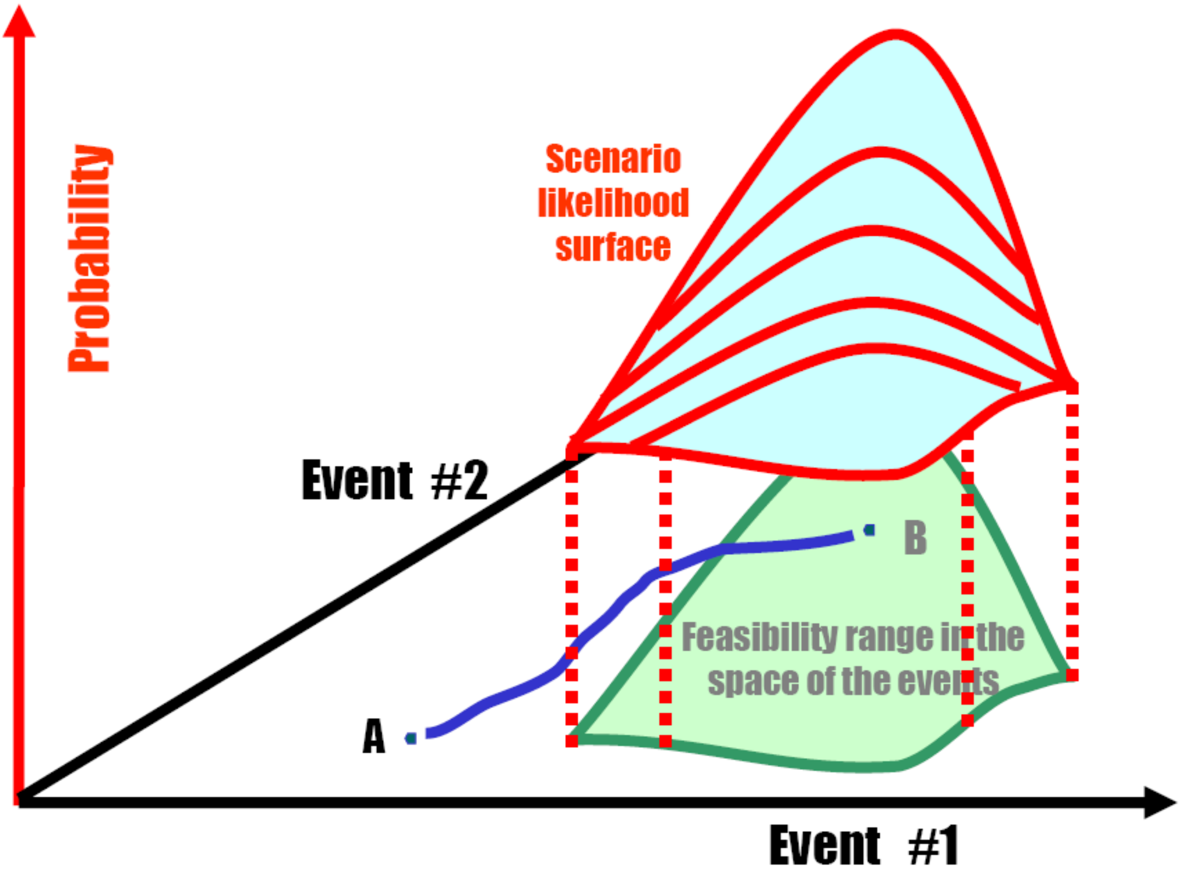

Figure 11: From the present (A) to scenarios (B): feasibility range and probability

4.2 Theoretical approaches[19]

A 'prescribed' method for scenario building does not exist, but a considerable amount of tool kits is available to analysts[20]. The most-used long-term methodologies can be grouped in four main classes, within which there are several subcategories.

1. The simplest method projects the main elements of the system (macro-variables), independently from one another; main categories in this group are trend projections and, partly, end-use analyses.
2. Other methods project the relation between the elements; main techniques in this group are econometric projections and simulation techniques, mostly in combination with the categories of the first group.
3. A third method projects the system as a whole, where new elements and new relations can appear in the long term; main categories in this group are systems dynamics and economic equilibrium modelling. Both can use either top-down or bottom-up approaches; most advanced techniques combine the two approaches.
4. A more recent method, aware of the fact that scenarios are subjective views of the future, start by portraying the desired plausible futures and then "backcast" them to (hook to) the present; main components of this techniques is Delphi analyses and sub-systems models.

Technology foresight will be treated separately (section 5), as well as methods of producing contrasted scenarios, which are intended to explore the widest possible area in the space of future events (section 6).

Each approach reflects a certain world view, which is often embodied in hidden assumptions about what is likely and what is possible. Trend projection and econometric methods are typically strongest when used in predicting what is likely to happen given continuation of current trends, whereas end-use, systems dynamics, and scenario analysis are generally most useful in assessing ranges of possible / plausible policy choices. Furthermore, before deciding the method, it is important to know whether the scenario building exercise has the availability of one or one thousand persons*month.

4.2.1 Trend Projections

The simplest assumption is that the future will be a smooth extension of the past. Key variables are identified and described in terms of time trends or correlation with other variables. The simplest and oldest trend approach is drawing straight lines on graph paper. Two-parameter fits can easily be made using linear, log-linear, log-log, or other transformations.

Trend projections rely on empirical correlations. The approach can work well in the absence of structural change (i.e., for short-term forecasts). It is also helpful for business-as-usual forecasts, which generally see the future as a smooth continuation of historical growth rates. Trend projections often assume (sometimes implicitly) the presence of exponential processes. The "exponential assumption" is so deeply embedded that economists often use terms like "steady state" or "constant" to refer to fixed rates of change (e.g., fixed GDP growth rates) rather than fixed levels.

A major weakness in trend-projection approaches is that they discourage searches for underlying driving forces. Typically these models do not include causality and cannot identify emerging contradictions, both of which can be critical in understanding how the future might unfold.

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[19] For an excellent discussion of scenario building processes see [Schwartz, 1996]. In what follows, long term refers to 2100, strictly speaking; however for their importance, also medium term scenarios (with a time horizon of 25-50 years) and their methods are taken into consideration.

[20] Armstrong discussed forecasting techniques in 1978, and two decades later edited a comprehensive review of forecasting principles [Armstrong, 1978, 2001]. Armstrong's handbook discusses and assesses many types of forecasting, including some techniques (e.g., neural nets) apparently not yet used at all in long-range energy scenario building. The Journal of Forecasting publishes technical articles on virtually every technique [Green, 1985; Ascher, 1978].

4.2.2 Econometric Projections

Econometric approaches are a straightforward extension of trend analysis. The approach is made possible by modern computers. Whereas trend analysis is basically a graphical technique used with one independent variable, computers make it easy to explore relations among many hypothesized causal variables. Dependent variables, such as energy consumed or carbon emissions may be correlated with independent variables such as price and income.

Econometric analysis relies on regression analysis of historical data and thus assumes structural rigidity in the economy. Sanstad et al. note that some proponents of this method have proclaimed the importance of dynamic market forces, whereas their preferred analytical technique assumes economic rigidity [Sanstad, et al., 2002].

Just as for trend projections, the strength of econometric techniques is in short-term forecasts, when structural changes and technology adoption are limited in their effects because of the inherent lags in stock turnover. They become less useful for longer time frames, because of the greater likelihood that the past experience on which the econometric parameters are based will no longer reflect future conditions.

Despite their complexity, econometric models do not necessarily outperform the simpler trend-projection approach to regression forecasting. An analysis of the accuracy of utility projections during 1972-1982 concluded that "in all sectors, econometric techniques fail to outperform trend extrapolation/judgmental techniques" [Huss, 1985]. Whereas this result may not be general, it points toward one of the key conclusions of [Armstrong, 2001], that simple models can sometimes yield results as accurate as more complicated techniques.

4.2.3 Energy system projections

Projecting the energy system as whole in order to build consistent scenarios can start only after in depth analyses of the complex system whose future is going to be explored.

Real systems are open to, and interact with, their environments. They acquire qualitatively new properties through emergence, resulting in continual evolution. Rather than reducing an entity (e.g. the human body) to the properties of its parts or elements (e.g. organs or cells), systems theory focuses on the arrangement of, and relations between, the parts which connect them into a whole (cf. holism). This particular organization determines a system, which is independent of the concrete substance of the elements (e.g. particles, cells, transistors, people, etc)[21].

Systems analysis applies systems principles to aid decision makers identifying, quantifying, optimising and controlling socio-technical system. It takes into account multiple objectives, constraints and resources. It aims to specify possible course of action, together with their risks, costs and benefits[22].

Practically, the analysis of a complex system begins with the identification of the main components:

- Boundaries (space, time, logic, etc.),
- Elements and characteristics,
- Connections,
- Dependencies (rules, quantitative relations),
- Economic Interests and Decision Makers.

Then each component of the system is characterized quantitatively with the available data describing several dimensions: energy, engineering, economic and environmental. In fact other dimensions enter the characterisation, although not all in quantitative terms.

[21] Quoted from http://pespmc1.vub.ac.be/SYSTHEOR.html.
[22] See Principia Cybernetica web.

Normal energy statistics don't help much in the first instance, because they focus on a single element or at most, on a subsystem. Due to the lucky circumstance that all forms of energy can be measured with a common unit, from the early fifties and even more since the 1973 oil crisis, experts compile annual national energy balances (NEB; see example reported in Table 5 and Table 6). NEBs have the advantage of encompassing all energy flows and of checking input with output, as in economic accounting sheets. In the most common formats NEB balance primary energy (extracted from mines, oil & gas fields, etc.) and final energy (energy invoiced to the final consumers). In order to study the full system, analysts extend the NEB to a third stage, where the demand for energy services required by consumers (motor drive, transport, space heating, etc.) are satisfied by end use devices (cars, domestic appliances, heating systems, etc.).

Since energy systems have high technological content, the attention is focused less on the energy that flows through the system and more on the devices that extract primary energy, transform one form of energy into another, transport distribute, consume final energy and convert it into useful energy that satisfies the demand of the consumers. But it would be impossible to keep track of the million devices that operate an energy system. For practical purposes, plants processes devices and their vintages are grouped in homogenous groups, called technologies. The first distinction is between the stock of existing technologies and the new technologies available on the market. The graph, which represents schematically all the technologies and all the flows of energy fed into, and returned from, each technology, is called the Reference Energy System (RES, see Figure 12). The characterization of energy technologies is a daunting task for analysts, because the equivalent of the NEB for technologies is rarely and incompletely compiled.

The economic dimension of the system is brought in first in the characterization of each technology, where cost parameters are included (investments, operating and maintenance, fuel, additional), and the production costs are calculated. However, the central information in a market economy is the market price of energy goods or energy related commodities. Practically, in tables with the same format of the NEB, the analyst reports for each commodity and stage average yearly market prices together with the total yearly quantities. The overall economic value of the energy system (extensive value) is calculated by multiplying the quantities (another extensive value) by the prices (intensive values) and made consistent with the main national macroeconomic and microeconomic sectoral data.

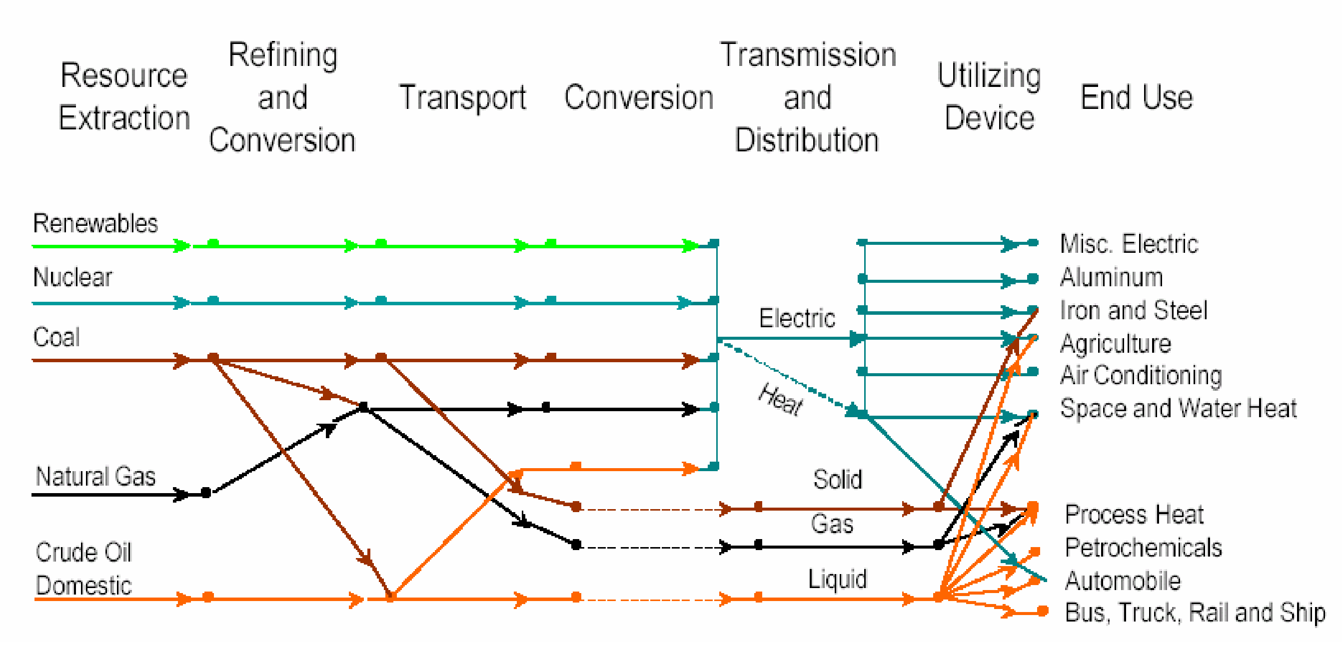

Figure 12: In energy systems analyses the Reference Energy System represents the technical part

The environmental dimension is already included in the characterization of each technology, where emissions factors are reported (intensive variables). Yearly emissions and inventories of pollutants and greenhouse gases (GHG) by species (extensive variables) are re-aggregated in the same format of the NEB, with additional dis-aggregations where necessary. When the energy, engineering, economic and environmental dimensions of the system have been characterized, analysts identify the underlying relationships among the elements inside the system and between the systems and the set of elements that have been left outside.

4.2.4 "Backcasting" methods[23]

Backcasting is a term introduced by [Robinson, 1990] described as follows: "The major distinguishing characteristic of backcasting analysis is a concern, not with what futures are likely to happen, but with how desirable futures can be attained. It is thus explicitly normative, involving working backwards from a particular desirable future end-point to the present in order to determine the physical feasibility of that future and what policy measures would be required to reach that point.

A backcasting study meets the following criteria:

- The scenarios chosen in the project must reflect solutions to a specified societal problem.
- Starting with desirable futures, scenarios try to show a way to reach these goals, mainly by policy measures.
- Whereas a forecasting approach relies almost entirely on causality, a backcasting approach becomes interesting if one is inclined to see teleology as a specific form of understanding.
- In econometric forecasting, the problem of uncertainty is usually treated by testing the sensitivity of the model results to variations in external variables, which is inadequate when investigating the distant future; backcasting studies may make an important contribution to the process of forming the future society by broadening the scope of solutions to strategic societal problems that are being discussed.

Long-run scenario building models generally assume that there exist underlying structural relationships in the economy that vary in a gradual fashion. The real world, in contrast, is rife with discontinuities and disruptive events, and the longer the time frame of the forecast, the more likely it is that pivotal events will change the underlying economic and behavioural relationships that all models attempt to replicate.

In the study of highly complex long-term sustainability problems a backcasting approach is an interesting alternative to the traditional forecasting approach. While the latter is based on dominant trends, the former is better equipped to encompass discontinuities and breaking of trends, which become likely in increasingly long time horizon.

4.2.5 Technology foresight

Foresight can be defined as the application of a systematic, participatory, future-intelligence gathering and medium-to-long term vision building to impact present day decisions and mobilize joint actions ([EURENDEL, 2003] and attached references). Foresight techniques[24] offer a means for strengthening the relations and interactions across institutional boundaries, so that knowledge can flow more freely among constituent actors, thus improving the efficiency of the knowledge system as a whole. The combination of analysis and communication processes in foresight exercises fulfils several functions:

- It is a collective and consultative process, with the process itself being equally important as the outcome;

[23] Quoted from the final report of the EC project Very Long-term Energy Environment Modelling (VLEEM)
[24] Although formal modelling is not central in this approach, some models with two factors Endogenous Technology Learning (ETL) by doing or by searching, such as ERIS of IIASA, MARKAL-TIMES of ETSAP, can support the main findings [Barreto, 2004].

- It identifies important emerging technologies, which are needed for achieving wealth creation and quality of life; and
- It supplies decision support for setting priorities in research and development to match the supply of technologies to future needs in an era of tight budgets.

In short, it assures the five Cs:

1. Concentration on the longer run,
2. improved Co-ordination between visions, intentions and actions of stakeholders,
3. Consensus on areas that seem promising,
4. Communication about societal needs and S&T opportunities, and
5. Commitment to the implementation of the policies that may be appropriate in the light of the exercise.

This is a condition for a closer alignment in the articulation, execution and exploitation of research efforts.

Since it is applied for a more comprehensive assessment of future energy technologies, this technique has lower ranges of subjectivity and uncertainties. When technological progress and innovation are projected, the space of possible events is smaller than when market quantities and prices are projected. This depends basically on the fact that technical parameters, such as efficiencies or lifetime have theoretical limits, while market prices and partly quantities have not. Therefore it is customary to talk about technology foresight. However the word seems too ambitious, because here too we are far away from knowing how the future will unfold.

4.2.6 Morphological analysis for building contrasted scenarios[25]

"Morphological analysis aims to explore possible futures in a systematic way by studying all the combinations resulting from the breakdown of a system". [EURENDEL, 2004] [26]

The process of "breaking down" the system implies the definition of a set of "components", which could develop into different directions. These possible developments are formulated as "hypotheses" or "configurations". The total number of combinations represents a "morphological space", which must then be narrowed down to several coherent sets by formulating certain conditions ("exclusions" and "preferences"). From the methodological point of view it is important that:

- The hypotheses about possible future developments are developed independently for each component (and if possible by different persons) in order to avoid a conscious or unconscious "predetermination" of possible constellations.
- The selection process on the basis of "exclusions" (incompatible pairs of hypotheses) and "preferences" (pairs of hypotheses, which would work well together) is crucial for the final development of the scenarios and should therefore be done during a futures workshop, preferably by professionals who have not been involved in defining the input.

Due to the large number of hypotheses to be checked against each other, practically the morphological analysis is divided into three consecutive steps:

- Selection of the most probable sets of hypotheses for the key drivers and determinants, thus defining the framework for three basic scenarios;
- Selection of the preferential set of instruments for each scenario; and
- Cross-checking of all hypotheses related to the considerable number of "instruments" in order to exclude contradictions within each of the scenarios.

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[25] This approach has little in common with other tools used for generating scenarios. For instance at IIASA, the Scenario Generator tool (SG, [Nakicenovic, 1998] includes historical economic and energy time series, and a set of regression equations. Input to SG are future population trajectories plus key parameters determining regional per capita GDP growth. The SG calculates final energy trajectories for each region and provides the user with some guidance for likely range of key economic and social variables for building plausible scenarios.

[26] See http://www.izt.de/eurendel/survey_results/index.html

An initial Cross-Impact (or Structural) Analysis helps defining the following inputs:

- Key drivers (highly influential factors largely controlled by the actors involved),
- Determinants (highly influential external factors, which may act as motors or restraints), and
- Instruments (also called "regulatory variables"), which can be employed in order to achieve a desired future situation

In the example of EURENDEL, the 2 key factors are "Impact of climate concerns" (3 hypotheses) and "Political support for sustainable development" (2 hypotheses), the 4 determinant (motors or restraints) are "Petroleum War" (3 hypotheses), "Supply interruption risk for gas" (3 hypotheses), "Mainstreaming ecology on a political level" (2 hypotheses) and "The perception of technological risk in society" (2 hypotheses). The possible evolution of each of these drivers and determinants was sketched in sets of two or three hypotheses each, using, whenever possible, qualitative and quantitative input from related research projects and scenario exercises. Example of hypotheses used for scenario building for the key driver "Impacts of climate change concerns" are:

- A1: Low political priority of climate concerns
- A2: High political priority of climate concerns / long-term impact mitigation
- A3: High political priority of climate concerns / high impact

The working group determined additional preferences and exclusions. A computer based tool, which depends upon a Boolean algebra concept, calculates the sets of possible solutions with the highest degree of coherence, out of the 216 possible combinations.

4.3 Formal models as scenario building tools

Models are simplified representation of reality. A model that could replicate exactly the real world would be useless. A road map reproducing every element of the landscape would serve drivers very poorly. Road maps concentrate on the roads and omit most characteristics of buildings and establishments surrounding them. The mock-up of an airplane can be used to study aerodynamic properties of a particular wing in a wind gallery, but does say how comfortable passengers will sit in the real plane. A painting is a graphical model able of transmitting emotions. But it does not answer questions about the cost of painted buildings or their thermodynamic properties. Such questions could be answered by a different graphical model, such as the executive project of an architect. The world model automatically subsumes among its semantic meanings the concept of simplification. In this sense, strictly speaking, no model is fully true. When a model is built, we have in mind a specific purpose and we want to answer some sets of interconnected questions. Therefore, in front of a model, it is necessary to be always aware of its limits and of the list of questions the model cannot answer. [Meadows, 2002]

Models can have different forms: mental, verbal, graphic, mathematical, physical, economic, etc. Words such as growth, population, forest, water are no more than symbols, verbal representations of much more complex realities. Graphs, diagrams, maps or photographs are plane graphical models, where relations are represented by positioning objects in a surface. What follows describes mathematical models, where (quantitative) relations are represented by sets of mathematical equations. Mental models are abstractions sitting in our mind. They are informal and nobody can access them directly. For their very nature, formal models are can be observed, and manipulated by others. Ideally the two levels should interact: through formal models we can learn something about reality and the mental models of other people, and improve our own models. This learning process enables us to create better models. [Meadows, 2002]

Scenario studies make use of formal models in order to ensure consistency, reproducibility and transparency. Since scenarios are complex vision of the future, several models of different types (and databases) are used together, each one providing answers to different aspects of the future. Mostly the different models are soft-linked, in some cases they are hard-linked and form new – hybrid – models.

4.3.1 Econometric models

The earliest energy scenario exercises were base on simple econometric models. They analysed the historical trends of the most important macro-economic variables related to energy: population, GDP, energy consumption, prices, etc. They assumed econometric relations among macro-economic variables and estimated the actual coefficients through regression methods applied to time series (exceptionally to cross-sections). The model can be as simple as one equation or as complex as to include more than one thousand equations.

The weak point of this method is the assumption that past macro-economic relations can be extrapolated to the future. The longer becomes the projected time horizon, the greater becomes the distance of the projected macro-economic variables from economic equilibrium conditions. Furthermore, econometric projections could bring in the long term to the violation of physical laws, such as plant efficiencies or available space and time of the final consumers.

Models always have static components, but except for invariant physical laws, there is nothing static in the economy. Energy scenarios necessarily make assumptions about human behaviour (including social, institutional, and personal) and human innovation. Institutional behaviour evolves, individual behaviour changes, and pivotal events occur, affecting outcomes in ways we cannot anticipate. Static structure models cannot keep pace with the long-term evolution of the real world, not just because their data and underlying algorithms are inevitably flawed, but because the world sometimes changes in unpredictable and unforeseeable ways.

4.3.2 End-use and simulation models

During the 1970s scientists developed detailed engineering-economic analyses of the potential for energy efficiency, such as the technical study carried out by the American Physical Society [AIP, 1975] and the EC MEDEE project[27]. The general conclusion of essentially all these "bottom-up" analyses was that energy efficiency was far below levels that made economic sense from a societal perspective. The 1973 and 1979 oil shocks gave impetus to a focus on efficiency and resulted in major changes in the relationship between energy use and economic output, changes that remain in place today. A new impetus to build and use simulation models came from the debate about the cost of climate change mitigation policies. The point of view of environmentalists in using these tools is well represented by [IPSEP, 1987-97].

Presently the best known and more widespread[28] tool based on this approach is LEAP, the Long-range Energy Alternative Planning system, developed by the Stockholm Environment Institute and the Tellus Institute, Boston (MA). It is an integrated energy-environment modelling tool[29] based on a comprehensive accounting of how energy is consumed, converted and produced in a given region or economy, under a range of alternative assumptions on population, economic development, technology, price and so on. With its flexible data structures, LEAP allows for analysis as rich in technological specification and end-use detail as the user chooses.

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[27] MEDEE is a simulation model designed to evaluate the long-term energy demand of a country in combination with a scenario description of the main aspects of the country's social, economic, and technological evolution is described. Parameters taken into consideration are end-use total demand by category (e.g., residential space heating, service sector cooling, gasoline for intercity cars)and the potential market (maximum demand that can be technically met) for each final energy form (electricity, coal, gas, solar, oil products, and district heat). The model also calculates useful energy demand in each end-use category for which several energy forms can be used, thus determining the substitution possibilities is energy use. The scenario description is complemented with technological parameters (e.g., insulation standards, efficiencies, fuel mix), the evolution of which is specified in a way consistent with the macroeconomic assumptions.

[28] The tool is distributed free of charge and used by about one thousands groups in almost every country of the world.

[29] In other words, LEAP, as MARKAL-TIMES or MESSAGE, is not a model, but a model generator.

With LEAP, the user can go beyond simple accounting to build sophisticated simulations and data structures. Unlike macroeconomic models, LEAP does not attempt to estimate the impact of energy policies on GDP or employment, although such models can be run in conjunction with LEAP. Similarly, LEAP does not automatically generate optimum or market-equilibrium scenarios, although it can be used to identify least-cost scenarios. Important advantages of LEAP are its flexibility and ease-of-use, which allow decision makers to move rapidly from policy ideas to policy analysis without having to resort to using more complex models.

The end-use analysis approach disaggregates the energy sector into technologically distinct sub-sectors. Total projections are built up from detailed sectoral analyses of various end uses (e.g., lighting, cooling, refrigeration, heating, etc.). This approach begins by asking, "Who uses how much energy for what purposes?" Thus, it first focuses on the services that use the energy, then on the technological characteristics of the devices delivering those energy services.

Because these models explicitly represent end uses and the associated technologies, it is relatively easy to incorporate anticipated changes in technology and policy (e.g., automotive, refrigerator, heating plant, or lighting efficiency standards). The explicit characterization of equipment ownership in these models also allows saturation effects to be assessed (e.g., the saturation of residential central air conditioning will not greatly exceed 100% of the homes in any region; automobile mileage is constrained by the amount of time people are willing to spend travelling, etc.). Furthermore, because the approach embodies detailed representations of technologies, end-use analysis can account for physical limits (e.g., Carnot limitations or second-law efficiency constraints).

A downside of the end-use approach may be tendencies among practitioners toward excessive technological optimism or pessimism. Optimism places excess emphasis on new structure-changing technological devices, which may fail technically or in the marketplace. Conversely, pessimism results from preoccupation with incremental improvements to existing technologies, which may lead to overlooking structure-changing innovations. These approaches often fail to capture the impact of interactions between price and income within the larger economy.

4.3.3 Systems dynamics (bucket) models

The systems dynamics approach models engineering, social, and economic systems as combinations of reservoirs (buckets) that can accumulate and discharge quantities of interest (such as energy, population, and money). Flow paths, often representing nonlinear rate processes, link the reservoirs, creating feedback loops that define coupled sets of first-order nonlinear differential equations [MIT, 2006]. The modeling technique emphasizes dynamics and identification of key driving variables. Once a model's structure is fixed, it is exercised by varying parameters and driving forces.

Systems dynamics forces precise specification of assumptions. It avoids the almost automatic incorporation of exponential growth so characteristic of the top-down econometric and bottom-up end-use approaches. Exponential growth, when it occurs, always results from specific positive feedback mechanisms. Systems dynamics requires the modeller to identify the feedback path in order to obtain exponential growth (or decay).

Systems dynamics approaches to energy modelling have not been widely used for policy work, though they have been extensively used in university courses. Typically the approach has been applied at high levels of aggregation and abstraction. Systems dynamics modellers in the field of energy have not generally incorporated the wealth of detailed engineering, economic, and demographic data sets developed by the other approaches. Systems dynamics has been extensively used in other areas such as fisheries depletion and predator-prey relations [Ford, 1999].

The Limits to Growth and partly the Millennium studies mentioned in the previous chapter are built with the use of system dynamics tools.

4.3.4 Bottom up economic optimization models

Conventional Bottom-Up (BU) models describe the current and prospective competition of energy technologies in detail, both on t he supply-side (the substitution possibilities between primary forms of energy) and on the demand-side (the potential for end-use energy efficiency and fuel substitution). These models are helpful in illustrating the possibility for radically different technology futures, with significantly different environmental impacts. By the way they are built, they cannot violate the laws of physics and technology. However they have been criticised for not providing a realistic portrayal of either micro-economic decision-making by firms and consumers when selecting technologies, or the macro-economic feedback of different energy pathways and policies in terms of changes in economic structure, productivity and trade that would affect the rate, direction and distribution of economic growth. [Hourcade, 2006]

This type of models is well represented by the MESSAGE[30] model developed by IIASA [Messner et al., 1995] The Model for Energy Supply Strategy Alternatives and their General Environmental Impact (MESSAGE) is a systems engineering optimization model used for medium- to long-term energy system planning, energy policy analysis, and scenario development. The model provides a framework for representing an energy system with all its interdependencies from resource extraction, imports and exports, conversion, transport, and distribution, to the provision of energy end-use services such as light, space conditioning, industrial production processes, and transportation (across 11 macro-regions). Scenarios are developed by MESSAGE through minimizing the total systems costs under the constraints imposed on the energy system. Given this information and other scenario features such as the demand for energy services, the model configures the evolution of the energy system from the base year to the end of the time horizon (in ten year steps). It provides the installed capacities of technologies, energy outputs and inputs, energy requirements at various stages of the energy systems, costs, emissions, etc.

The degree of technological detail in the representation of an energy system is flexible and depends on the geographical and temporal scope of the problem being analyzed. A typical model application is constructed by specifying performance characteristics of a set of technologies and defining a Reference Energy System (RES) to be included in a given study/analysis that includes all the possible energy chains that the model can make use of. In the course of a model run, MESSAGE then determines how much of the available technologies and resources are actually used to satisfy a particular end-use demand, subject to various constraints, while minimizing total discounted energy system costs.

4.3.5 Top-down computable general economic equilibrium models

Conventional Top-Down (TD) models, in contrast, have addressed the consequences of policies in terms of public finance, economic competitiveness and employment. Since the late eighties TD energy-economy policy modelling has been dominated by computable general equilibrium (CGE) models, reflecting the decline in the influence of other macro-economic paradigms, such as disequilibrium models. CGE are assumed to represent real-world micro-economic responsiveness to policies, such as the substitutability of energy for other inputs or consumption goods. What CGE tend to lack, however, as do TD models in general, is technological flexibility beyond current practice. If the input substitution elasticities critical to technological response in TD models are estimated from historical data, there is no guarantee that the values for these parameters would remain valid in a future with ambitious policies for environmental improvement, i.e. shaped by induced technical change. [Hourcade, 2006] Furthermore, the observation of base laws of nature for the technological structure underlying the economic equilibrium is not ensured.

The simplest[31] and best known example of this modelling approach is MACRO, the top-down macroeconomic model developed by [Manne, 1992]. MACRO defines an inter-temporal utility function of a single representative producer-consumer in each of the model's world regions, which is maximized. The

[30] The original version of MARKAL [Goldstein et al., 1983] is of the same type.
[31] More sophisticated and complex economic models have been developed for instance by Hudson & Jorgensson or Nordhaus. See also the CGE global model GEM-E3.

main variables of this module are the production factors capital stock, available labor, and energy inputs, which together determine the total output of an economy according to a nested CES (constant elasticity of substitution) production function. The optimal quantities of the production factors are determined by their relative prices. Energy demand curves are given in two categories, electric and non-electric energy, as quadratic functions of energy prices. These functions are defined for the two categories and for all time periods. Actual demands are determined by MACRO in a way consistent with projected GDP. MACRO also disaggregates total production into macroeconomic investment, overall consumption, and energy costs.

4.3.6 Hybrid models

The need of combining different approaches for long-term energy environment scenario building came to prominence during the “efficiency-gap” debate of the eighties and nineties [Grubb et al., 1993]. On the one hand, TD modellers, notably CGE modellers, generally work with model forms that assume that competitive markets automatically allocate all inputs and final goods efficiently. This economic perspective a priori denies the existence of an energy efficiency gap – that there could be a quantity of energy efficiency that society could profitably achieve. On the other end, BU models demonstrated that there were significant ‘no-regret’ possibilities for increasing energy efficiency in the economy. The divergence of views, not yet resolved, had significant energy policy implications. The gap between the two representations of technology became even more noticeable when the policy debate refocused on shifting the economy to a technology path with dramatically lower greenhouse gas (GHG) emissions. Policy makers need to make decisions today about the magnitude and timing of energy environment targets, and about the specific policy package that would best achieve them in terms of the usual policy making criteria – economic efficiency, environmental effectiveness, and administrative and political feasibility. To do so they need to know the extent to which their policies might influence the characteristics and financial costs of future low or zero GHG emissions technologies, the likely willingness of consumers and businesses to adopt these, and the impact of policies on employment, competitiveness, and economic structure. Neither modelling perspective is able to give completely defensible advice for these requirements. [Hourcade, 2006]

To be particularly useful, an energy-environment economic policy model should perform fairly well in terms of three dimensions. It should:

1. Be technologically explicit, including an assessment of how policies to promote technology commercialization and diffusion might affect the future financial costs of acquiring new technologies.
2. Be behaviourally realistic, including an assessment of how policies to increase market share might affect the future intangible costs (specific consumer concerns and preferences) of acquiring new technologies; and
3. Have macro-economic feedbacks linking energy supply and demand to evolution of the economy’s structure and total output; this macro-economic dimension should include trade and financial feedbacks between countries in cases where the environmental challenge is one that requires a global effort, such as with GHG abatement and climate change mitigation. [Hourcade, 2006]

4.3.6.1 Combined econometric – end use approaches

Combined approaches employ both regression methods, when trends appear to be robust and end-use analysis when it appears to provide more insight. This kind of approach is being used increasingly in both industry and government, and especially by the utility industry [Huss, 1985]. Combined approaches bring together engineers and economists, allowing them to draw upon the best analytical tools of each.

The study "Resources in America's Future," published in 1963 by the then-new Resources for the Future (RFF), was a landmark assessment of the demand and supply of all major U.S. resources from 1960 to 2000 [Landsberg, et al., 1963]. The study combined economic and technical analysis. Economic factors were drawn primarily from U.S. government reports. The authors did a considerable amount of bottom-up trend analysis, supplemented by their professional judgment. Some assumptions are grounded in the laws of thermodynamics, but most energy technologies are so far from fundamental limits that these laws provided minimal constraint. Rather, technological innovation and human behaviour were the dominant factors, and these factors proved hard to anticipate.

The study's lead author, Hans Landsberg, revisited the report two decades later [Landsberg, 1985]. His perspective was philosophical: "[O]ne is a captive of the time of writing or calculating, typically without realizing it." In his retrospective review Landsberg remarked on the consequences of the failure to anticipate the oil embargos of the 1970s. The 1960--1980 period covers the embargo of the 1970s, which the 1963 study did not anticipate. Actual energy growth was higher than the RFF forecast from 1960--1970 and slowed dramatically thereafter. The RFF study showed no such "break-point." It assumed steady growth at a rate that led, fortuitously, to about the right outcome in 1980. The RFF forecasts become increasingly high in the 1980--2000 period as actual energy use continued to lag projected use (141 EJ primary energy demand in 2000 in the "medium" projection versus 103 EJ actual).

4.3.6.2 Bottom-Up technological least cost models with partial economic equilibrium properties

The standard version of the MARKAL-TIMES models generators combine now the technological details of a Bottom-Up least cost energy model with the economic equilibrium properties of the energy supply – demand sectors. A brief description of MARKAL-TIMES would express that it is a[32]:

- Technology explicit;
- Multi-regional;
- Partial equilibrium model;

that assumes:

- Price elastic demands; and
- Competitive markets: with
- Perfect foresight (resulting in Marginal value Pricing)

4.3.6.3 Combined detailed Bottom-Up technological least cost models with simple macro-economic models

The MACRO model has been hard-linked to several detailed bottom-up (BU) technological least cost models to give ETA-MACRO, MESSAGE-MACRO, MARKAL-MACRO, TIMES-MACRO. MACRO and the BU model are linked to include the impact of policies on energy costs, GDP and on energy demand. The link is established by using BU results on total and marginal costs of energy supply to derive the quadratic demand functions for MACRO. The linked model is iterated until MACRO's resulting energy demands do not deviate from BU's by more than a given fraction.

4.3.6.4 Combined macroeconomic, energy system and climate change models

The global optimization model MERGE (A Model for Evaluating the Regional and Global Effects of GHG Reduction Policies, [Manne, 2004]) describes the interaction between macroeconomic production, the energy system (demand and supply), pollutant emissions, and climate change. The model consists of three logical parts: a macroeconomic module, an energy supply part, and a climate module. It combines a top-down description of the economy and energy demand with a bottom-up description of the energy sector.

The macroeconomic module defines an inter-temporal utility function of a single representative producer-consumer in each of the model's world regions, which is then maximized by MERGE subject to given constrains. The main variables of this module are the production factors capital stock, available labor, and energy inputs, which together determine the total output of an economy according to a nested CES (constant elasticity of substitution) production function. The optimal quantities of the production factors are determined by their relative prices. The core of the energy module is a comparatively simple Reference

[32] Details can be found in the user's guide of MARKAL-TIMES, downloadable from www.etsap.org.

Energy System (RES) describing the technological options available to supply the energy needed as a production factor. The climate module calculates the resulting GHG concentrations and global temperature.

The MERGE model has been used to study the costs of the Kyoto Protocol under different schemes and emission trade assumptions. The model regions now include the key players of the Kyoto protocol as independent regions. This allows e.g. to investigate different emission trading regimes including exclusive trading within the European bubble (EU + extension countries), and with or without Ukraine. The model allows investigates the effect and timing of clean development and joint implementation mechanisms and includes all "Kyoto gases" and their abatement options.

4.3.7 Post-scriptum: are long range energy models 'validatable'?

Although building long term energy models looks necessary for long term scenario building, the validity of any such exercise cannot be established. Hodges & Dewar distinguish between what they call "validatable" and "non-validatable" models [Hodges, Dewar, 1992]. In their terminology, validatable models have the potential to yield predictions of the future in which one can have high confidence. Whereas non-validatable models can have many useful features, they are likely to have low precision and unquantifiable errors.

Situations describable by validatable models are characterized by four properties:

1. they must be observable,
2. they must exhibit constancy of structure in time,
3. they must exhibit constancy across variations in conditions not specified in the model, and
4. they must permit collection of ample and accurate data.

In some instances it is possible to forecast precisely and confidently. Astronomical and satellite orbital predictions are a clear example. Satellite orbits can be calculated with enormous precision because orbital mechanics passes these tests. This precision makes possible technologies such as the satellite-based global positioning system.

The fact that a model is validatable does not necessarily mean all properties of the future outcome can be predicted to any desired accuracy. Both quantum mechanics and chaos theory assess and quantify fundamental limits on prediction.

The situations modelled by long-range energy scenario building tools do not meet criteria 2 and 3 in the list above. Consequently, long-range energy scenarios, which are the product of those tools, are not validatable in Hodges & Dewar's sense.

4.4 Elements for a scenario taxonomy

4.4.1 Developing a scenario – Key elements and types

This type of exercise can be conducted at different scales and with different time horizons in contexts that range from the trivial day-to-day planning, to the strategic planning of an enterprise, to longer term plans for a country's infrastructure development. At the lower end of the scale we are used to performing this scenario-development process without giving it much thought: at the high end, considerable time and resources (both human and equipment) may be required.

While it is clear that scenario work at the scale needed to analyse global energy and environment futures is likely to require time and intellectual resources, we should not be satisfied with producing and using only one type of scenario.

This type of work, however, requires substantial effort because several scenarios, and as many internally consistent and plausible chains of events or storylines, have to be developed on the basis of the alternative outcomes of the critical uncertainty factors identified.

A fundamental requirement of scenarios is that they be internally consistent, logical and plausible constructs of how the future might unfold. Furthermore, scenario building is an inherently interdisciplinary process, because it needs to take into account the many dimensions of the same problem.

Scenarios need to integrate long-term phenomena (including demographic, technological or ecosystem trends) with shorter-term phenomena (like inflation or spikes in oil prices). And as mentioned earlier, they need to take into account possible departures from trend [De Jouvenel, 2000]. Scenarios should also possess the capability of challenging users' mental maps, because that is when a true possibility to learn exists [Davis, 1998].

The process of scenario building is a complex analytical exercise. Five main steps are discernible:

- define the problem and its horizon or isolate the decision that needs to be made;
- gather information, expert opinion and past data on the system under investigation and build a coherent system that includes all relevant actors and agents, including the factors and links (both quantitative and qualitative) between them;
- identify the key factors that would affect decisions and separate predetermined or unavoidable factors and trends from those that are highly uncertain or depend on will;
- rank these factors by importance for the success of the focal issue (defined in step 1) or by uncertainty and identify the two or three factors or trends that are most important and most uncertain; these will represent the main axes along which scenarios will differ and will be characterised. Predetermined elements/factors will remain unchanged in all scenarios; and
- flesh out the scenarios in the form of consistent narratives or "stories".

The next logical step is to examine the implications of the various scenarios and translate them into clear strategic choices. Different choices can at that point be tested for robustness/resilience against the scenarios outlined.

4.4.2 Types of scenarios

There are several types of scenarios: energy scenarios, emission scenarios, population-growth scenarios, agricultural development scenarios, etc. There is, however, no energy scenario that omits questions related to population and economic data. Emission scenarios that emphasize formulating ways to limit greenhouse gas emissions strongly depend on the development of energy systems. Consequently most energy emission scenarios can be summarized as scenarios of human development.

Another distinctive mark is the geographical frame, i.e. whether it is global, regional or local. Although the present study focuses primarily on global scenarios, it is important to point out that regional and local scenarios are essential in understanding the developments that cannot be perceived by a global approach. Studies like the one by [Reddy et al. 1991] for Karnataka India are a useful completion to OECD-centric approaches.

Not all scenarios are surprise-free. [Toth, 1989] describes the interactions between development and environment as follows: "But history shows that discontinuities, thresholds and - more generally - surprises are more the rule than the exception in such interactions, exerting a major influence on their outcome." To counterbalance the discrepancy between surprise free-scenarios and surprise-driven history, scientists have developed a number of so-called "Surprise-rich" Scenarios. Additionally, [Anderberg, 1989] made a distinction between Exploratory Scenarios and Anticipatory Scenarios, [Alcamo et al. 1995] distinguished between intervention and Reference Scenarios, [Nordhaus and Yohe, 1983] between probabilistic and non probabilistic scenario analysis.

[Ygdrassil et al. 1989] categorized energy scenarios by the approach used in selected publications: the End use approach [IIASA/WEC 1981b], the Economic approach [Edmonds & Reilly 1985], [Nordhaus & Yohe 1983], the Expert opinion approach [WEC, 1983], the international Energy Workshop approach (as a variation of expert opinion approach) and the Phenomenological approach [Marchetti, Nakicenovic 1979].

4.4.3 *Exploratory vs. normative scenarios*

The type of scenario with which we are most familiar is the reference scenario of the forecasting type, which assumes the continuation of historical trends into the future and that the structure of the system remains unchanged or responds in predetermined forms.

This type of scenario is often referred to as a "business-as-usual (BAU) scenario". In consideration of the inertia of many of the systems under investigation, a short to mid-term forecast is often viewed as a scenario with a high probability associated to it. But when projected over a longer time horizon those trends may turn out to be extremely unlikely. The system may be, for instance, close to a turning point, or display previously undetected chaotic features. Some of the underlying factors that drive an energy/environment system (including, for instance, technological development, degree of openness of markets, social structures, environmental values held by the people, and so on) are much less predictable. However, over periods of 30 to 50 years, it is precisely these factors that are the most important. And it is in this medium-long-term horizon (30-50 years out), that many of the critical environmental issues become most pertinent. For example, climate change and the growth in emissions that lead to global warming have their impact over a period of 100 years – with the near term path only critical in how it affects longer-term, cumulative emissions. Therefore, over the long run it is difficult and risky to base one's future strategy uniquely on BAU scenarios and forecasts. Policy scenarios, designed to analyse the impact of introducing a new policy in a context that in every other respect reflects the continuation of present trends, often present many of the same limitations of BAU scenarios.

Exploratory scenarios, on the other hand, are designed to explore several plausible future configurations of the world. The purpose is of identifying across those scenarios the most robust strategies from the standpoint of the subject that undertakes the exploration. From the point of view of designing strategic action, it is often plausible scenarios running counter to conventional wisdom that are the most fruitful. To a large extent, agents (individuals, businesses) and societies have the capacity to shape their own future, and often have the means to implement their vision. The task then becomes one of identifying the necessary steps and the roadmap to get there: in the case of energy and the environment steps refer to policies needed, R&D policy, and so on. In this second case scenarios are of the "normative" type, and the path to their implementation is outlined through a "back-casting" process.

Normative scenarios can be designed on the basis of a set of desirable features (or "norms") that the future world should possess according to the agent elaborating the scenario. This type of scenario is inherently policy oriented and prescriptive. That is to say such scenarios assume that policy actions can shape a future in the desired image, and they are designed to identify the policy actions required.

The scenario process outlined above corresponds, strictly speaking, to that of so-called "exploratory" or "descriptive" scenarios, built for the purpose of exploring a range of outcomes and analyse their implications for strategic decision-making.

The main value added in exploratory scenarios lies in the fact that they help prepare for turns of those events that are plausible and entirely possible without representing a straight-line continuation of past and present trends. They are particularly useful in proximity to bifurcations, especially when a hint of such a situation takes shape in present day phenomena. And they can help enormously to accelerate and calibrate the response to new developments (both positive and negative ones).

Scenarios, however, can also be "normative" or "strategic". In this case the perspective is changed: a "desirable" vision of the future, or a goal in the future, is outlined. What is considered "desirable" clearly depends on the general objectives of the individual or group elaborating the scenario. An example could be a sustainable scenario characterised by stabilisation of GHG concentrations at 450 ppm by the end of this century. These objectives are used as a point of departure from which to travel backward and identify the conditions that must be fulfilled or measures to be taken at different stages along the path in order to implement that vision or achieve that goal. Typically, normative scenarios tend to work in a "back-casting mode".

This represents a critical change of perspective. It provides a useful mechanism to focus attention on several crucial elements: actions that must be taken and conditions that must be created at certain points in time in order to make the scenario achievable. The emphasis is on planning to achieve a certain result rather than on preparedness in responding to uncertain events. The attitude is more proactive, and policy intervention is a tool of choice.

Building a normative scenario requires rationalisation at the initial stage in order to define desirable characteristics of the future state of affairs, and to express them as measurable targets. Furthermore, the exercise stimulates formulation of critical questions, the recognition of uncertainties, the identification of bottlenecks and priority areas for policy action as well as for research and technological development.

While "exploratory" scenarios set the groundwork to describe what could happen, "normative" scenarios help decide what one could or should do, and hence are more concerned with action. In practise, normative scenarios of this type are rarely found in isolation, i.e. without previous analysis of what the future might bring [De Jouvenel, 2000] [Greeuw et al., 2000].

Another common distinction is between "qualitative" and "quantitative" scenarios. The former are pure narrative stories describing how the future might unfold or the relationships internal to the system analysed, without the help of figures. The latter also give a numerical illustration of the evolution of key variables or indicators. Quantitative scenarios are often represented through the use of a model, but may be also illustrated through much simpler tools.

Narrative scenarios can more easily accommodate an interdisciplinary perspective and the complex interrelationship of a system than can quantitative models. However, policymakers are likely to be more interested in scenarios offering quantified, credible representations of policy measures and their impacts, and that say something about the time path of the system's response. Since a minimum level of quantification is useful to test the validity and consistency of the scenario, scenarios are often simulated with the use of modelling tools.

As a general criterion, however, because any given model can only represent and analyse a given specific system, the model used to simulate a certain scenario must be a good match for the scenario. The choice of the model(s) to quantify a scenario depends on the scenario to be illustrated and on the specific issues or uncertainties that a scenario tries to illuminate. Therefore, the level of aggregation of the model, and its analytical focus, must be adapted to the focus and purpose of the scenario. This criterion applies both to the representation of an exploratory scenario and to the simulation of a normative scenario.

In order to quantify an exploratory scenario, the storyline and its main drivers must be "transposed" into a set of characteristic "exogenous variables" and corresponding values in the chosen model, which is then run until it adequately represents the underlying story.

To represent a normative scenario, the desired characteristics of the future world can be expressed either as exogenous variables or as targets (often constraints) for the chosen model, depending on the characteristics considered. The results of the model runs may provide a time path for relevant variables as the system adapts to the planned vision, and useful insights on some of the limits or bottlenecks it is likely to run into on its way to achieving the targets.

Other scenarios that are increasingly popular are policy scenarios, designed to analyse the impact of introducing a new policy in a context that in every other respect reflects the continuation of present trends. Scenarios of this type can be considered as a more restrictive subcategory under the general normative scenario category.

It is important to remember that the main function of scenarios is to help explore the main uncertainties lying ahead, by making them more explicit. Model quantification of scenarios by giving a more "precise" representation of a scenario may induce, especially in lay people, the illusion of accuracy, which is counterproductive with respect to the purpose of a scenario exercise.

5 Long term energy scenarios in practice

5.1 Introduction: why do we build long-term scenarios?[33]

Scenario building has become an essential tool of modern society. In fact it seems one of the main differences of modern over ancient history societies. It is hard to imagine a government action or investment decision not based upon some prior projection exercise. For example, investment decisions in power plants or home insulation are routinely assessed using economic techniques that require assumptions about future energy prices, which depend in part on assumptions about future energy demand. New technologies often come into existence if someone anticipates a market.

Global climate change is a particularly salient example of an environmental problem whose solution requires very long-range projections, imperfect though it may be. At its best scenario building contributes to better social decision-making and minimizes adverse side effects, both direct and indirect.

However, basing our long-term strategic decisions on the assumption of continuation of present trends presents risks: what if things do not turn out to be as expected? That possibility must be taken into account if we want to have a contingency plan at all. In particular, we need to contemplate the possibility that some critical variables, the ones that have the potentially largest impact in the success of our plan, take a different course. What do we do in that case? And, more generally, what strategy or course of action would maximise our chances of success in a wide range of different situations?

Furthermore, even assuming continuation of present trends we are often obliged to see that those trends may not necessarily lead to desirable outcomes. Trends may be unsustainable under a number of aspects. Developing through logical reasoning the final consequences of those trends may point to some clear dangers down the road. Should we not then try to steer clear of those dangers by modifying our trajectory? The intellectual exercise of looking farther into the future can be extremely useful to provide early warnings, in time for us to engage the possibility of actually modifying our behaviour.

These facts lead to two important considerations:

- over the long term a thorough understanding of the main elements of uncertainty is the basis for any strategic planning; and
- over the longer term an additional element of freedom comes into play inasmuch as the future can be shaped by political will.

Usually, the way the future is explored is through scenarios. These, in simple terms, are conjectures about what could happen in the future based on our past and present experience of the world. Hence, to build scenarios, soft or hard data about past and present trends are a necessary ingredient. Plausible conjectures about how these trends may further evolve in the future are the other element. The fact that all scenarios remain inherently speculative in nature diminishes neither their role nor their usefulness, which is mainly to assist in decision-making by offering the possibility of identifying problems, threats and opportunities. By examining an internally consistent and rational chain of events and trends that may follow from present actions, they allow a better assessment of alternative policies. For this reason the exploration of the future is often referred to in the literature as "scenario planning".

Identifying factors that affect GHG emissions paths over a 50-year period would be helpful in making policy choices. Similarly, environmental implications of new technologies may demonstrate critical path dependencies over a similar time frame – particularly in the energy sector, where capital stock turnover of large-scale power plants is usually measured in terms of 30 or more years. Exploratory scenarios thus can:

- help scientists and policy analysts to identify the main dimensions and drivers that shape those future worlds;

[33] Mostly quoted from [Craig et al., 2002]

- help them to explore and understand the dynamic links among the main drivers and to assess their relative importance (in terms of potential impacts) as sources of uncertainty;
- allow a more systematic and full appreciation of the uncertainties that lie ahead in the energy and environment domain.

Exploring and identifying the uncertainties over such factors becomes critical in order to formulate "least regret" strategies that, given the uncertainty, produce the fewest drawbacks, if not the greatest benefits. Those strategies that minimize regrets over different possible outcomes can then be valid candidates for implementation. The potential implications for policy of this type of scenarios are clear. In this case scenarios are used in their "explorative" mode, for strategic planning purposes.

Analysing the intersection between energy and issues of climate change mitigation requires the adoption of a long-term perspective. Energy infrastructure takes time to build up and has a useful life that for some plants is measured in decades. New energy technologies take time to develop and even longer to reach their maximum market share. Increasing concentration of greenhouse gases from human activities affects ecosystems and global climate over a long period – from decades to centuries. Policy responses to the threats of climate change manifest effects on emissions that can be appreciated after an often considerable delay. An analysis that seeks to tackle energy and environmental issues needs to look ahead at least to the next thirty to fifty years.

5.2 Function of energy scenarios[34]

In spite of using non-validatable models in the sense of [Hodges & Dewar, 1992], long-range scenario building portrays consistent, possible, plausible and probable vision of the future, which are practically useful within their base limits. Interestingly enough accurately projecting the future does not appear in the discussion, because the use is of scenarios is for the present, not for the time, which projections refer to.

The great variety of scenarios can be directly applied to policy and decision making as well as to implementing long-term planning[35]: “A scenario is a perfect tool to force policy makers to think big.” [Pratt, 1974] further continues that “this can mean to think globally, take longer time-scales into consideration, be more imaginative than in every day thinking etc.; in short, they open wider perspectives in thinking and discussion. An essential quality of scenarios is that it makes the future more concrete, touchable and opens the field for a constructive discussion about it”. The question to what extent scenarios are used to fulfil these functions is outlined hereafter.

5.2.1 Bookkeeping devices

In this use models are a means to condense masses of data and to provide incentives for improving data quality. Consider an energy projecting model that disaggregates energy use by economic sector and within each sector by broad end-use category. Using this model to project future energy demand, even by trend projections, may point to a lack of good data in some end uses or sectors, thus inducing better data collection. Comparing energy supply data with energy use data may disclose inconsistencies due to reporting errors, overlooked categories, losses, etc. For this purpose a model can be considered useful if it confirms that outputs correctly add up to inputs, or if its use reveals shortcomings in existing data quality and induces improvements in the quality of data collected in the future.

Scenarios that disaggregate to high levels of detail are necessarily complex and data intensive. This type of projection can only be carried out with large staff and substantial budgets. Such detailed projections may be required for applications focusing on details of specific sectors (e.g., assessing sectoral carbon dioxide emissions). One should be careful in using such projections, because deeply buried assumptions may drive high-level results in ways that are not easy to understand.

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[34] Quoted from [Craig et al., 2002]
[35] [Anderberg, 1989] quotes [Pratt, 1974]

5.2.2 *Aids in selling ideas or achieving political ends*

Within a month of the first oil embargo, U.S. President Nixon (then battling Watergate and under pressure to respond aggressively to OPEC cutbacks in production) announced "Project Independence," an energy plan that was claimed would lead to the reduction of U.S. oil imports to zero by 1980. The declared goal was "Self-sufficiency by 1980 through conservation and expanded production", but the figures had little or no analytical basis; they were sketched to support a policy goal. As was almost immediately predicted by some energy experts, the goal failed: imports were higher in 1980 than in 1973.

A more subtle example is shown in Figure 13. This is from a 1962 report prepared by the U.S. Atomic Energy Commission [JCAE, 1968]. It was designed to sell nuclear power plants by making the argument for sustained growth in electricity demand. The analysis was based on historic growth rates of total electricity and optimistic projections of the costs of nuclear power. The citation is a Congressional hearing that includes testimony describing the kinds of reasoning used. As a result of this optimism, utilities subsidized early nuclear plant orders (often with considerable help from the government, such as the Price Anderson Act limiting liability). Following the Organization of Arab Petroleum Exporting Countries (OAPEC) oil embargo of 1973 and the oil shock in 1979, electricity growth rates dropped to a few percent per year. The cost of nuclear plants did not decline as predicted, and by the 1980s orders for new plants vanished.

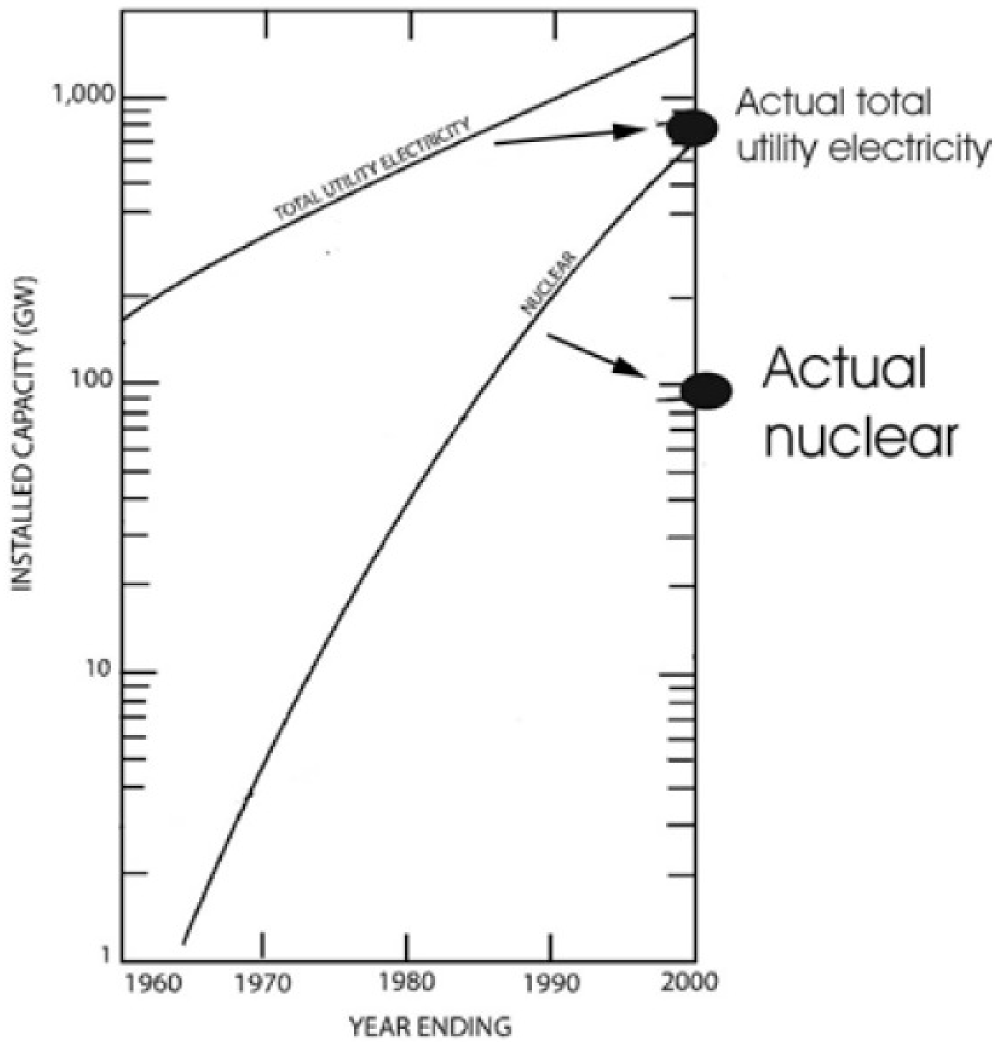

Figure 13: An U.S. Atomic Energy Commission forecast from 1962

An analysis may be used to provide an appearance of concern and attention for the benefit of constituents or the general public. It is not uncommon for advocates to cite reports selectively or out of context for promotional purposes. Similarly, studies may be used to provide a cover ("fig leaf") of technical respectability to a decision actually based on hidden values or self-interest.

Should a policy decision turn out to be ineffective, a politician may try to avoid personal criticism by implicating the analyst. Officials routinely take credit for success but disavow responsibility for failure. A DOE administrator put it this way: "Analysts must learn there is no fame for them in this business" [Greenberger, et al., 1983].

Studies can be commissioned as a delaying tactic. When all responses look like political losers, a decision-maker may commission an analysis to gain time and manoeuvrability. As additional facts come to light, the problem might resolve itself or a compromise might be arranged. Government agencies sometimes commission studies to moderate overly ambitious goals (e.g., as embodied in acts of Congress or presidential proclamations) toward more reasonable expectations.

Scenario analyses are not limited to qualitative story lines or simple quantitative indicators because before deciding investments and regulations, it is necessary to carry out comprehensive Cost Benefit Analyses. Scenarios give some arguments in support of future markets (quantities and prices) potentials that otherwise investment or regulation analysts should build anew with much less time and expertise.

5.2.3 *Aids in communication and education*

By forcing analysts to discuss data and analysis results in a systematic way, scenario building tools can facilitate communication between various stakeholders. The measure of success for this use is the degree to which the model improves understanding and communication, both for individuals and between groups with different mindsets and vocabularies.

For example, the population of a developing country at some future time might depend on childhood survival rates, longevity, female literacy, affluence, income distribution, health care, and nutrition. Modelling these influences could permit better understanding of interlinkages between them and improve communication between expert groups with diverse backgrounds. Such a model could inform, for instance, a government's long-term plans. Another example is the U.S. Energy Information Administration (EIA) Annual Energy Outlook forecast [US-EIA, 2006]. This widely used forecast, based on the EIA's latest analysis of the current data and industry expectations, provides a baseline that others can and do use for their own explorations of the future.

When a problem is being analyzed, word leaks out and leads to suggestions, ideas, and information from outside parties. This can add to the analysis directly, or stimulate helpful complementary work by others. A politician facing a thorny problem might commission a study to locate knowledgeable people. Thus, studies can identify talent as a by-product. The National Academy of Sciences CONAES (Committee on Nuclear and Alternative Energy Systems) study was directly or indirectly responsible for many career shifts. The American Physical Society "Princeton Study" held during the summer of 1973 was explicitly designed with this intent [AIP, 1975]. The oil embargos of the 1970s had led many physicists to think about making career shifts. The study gave them an opportunity to learn about energy issues, to meet and get to know experts, and to find jobs.

5.2.4 *Thinking and training aids to understand the range of possible outcomes*

The applicable measure of success here is the degree to which scenarios can prompt learning and induce desired changes in behaviour. The Limits to Growth model (discussed below) has been widely used to help students understand the counterintuitive nature of dynamical systems [Meadows, 1972]. Simulations and role-playing games have also been used to teach executives in the utility industry how new markets for SO2 emissions permits or electric power might behave. Experience with exercising these types of models can improve intuition for the behaviour of complex systems.

Models can enhance confidence through limiting or bounding cases. The Princeton Study [AIM, 1975] emphasized energy efficiency, with a focus on physical constraints to energy use. The cornerstone of the analysis was the concept of fundamental physical limits such as the first and second laws of thermodynamics. This work showed that great potential existed for improving efficiency by engineering change. Energy efficiency became a major theme of energy policy and remained so for long.

Scenarios can help people and institutions think through the consequences of their actions. Researchers often begin their exercises with baseline or "business-as-usual" projections, which attempt to guess how the world will evolve assuming current trends continue. Alternative forecasts are then created to assess the potential effects of changes in key factors on the results. For example, an economist might use such an analysis to assess the likely effects of a change in property taxes on economic growth in a particular state.

Computer models are excellent tools to teach people the dynamics of complex systems. The behaviour of these systems is often counterintuitive, so such scenario games can help people learn to manage them better.

Some projections are generated as part of scenario exploration exercises, which can be helpful any time a person or institution faces a critical choice. Oil companies, for example, are well aware that at some point the transportation sector may have to switch to some other fuel. Even though this switch may be a long time in the future, the prospect needs to be part of current contingency planning. Considering a wide range of scenarios can help institutions prepare for the many different ways the future can evolve. Institutions use forecasts to allocate physical and personnel resources. Some businesses have massive infrastructures with long time constants and find it useful to project over decades.

A scenario approach helps make assumptions explicit. At its best, scenario analysis can stimulate users to consider possibilities they had not conceived of before. The quality of the scenarios depends critically on the expertise and wisdom of the scenario-building team. The best scenarios highlight the possibility of structural changes. Scenarios are weak when they assume without careful reflection that the key drivers of the analysis will continue unchanged indefinitely.

5.3 What makes a good scenario?

In long-range projections "success" is a highly subjective term and the measure of success hinges on the intended use of the exercise. <u>Long-term scenarios are primarily useful for the perspectives they give to current users at the time the forecasts are freshly generated, not to future users</u>. Scenario studies can be evaluated against their objective and target (section 5.3.1), or method (section 5.3.2) or quantitative projection (section 5.3.3). However, the preferences of the 'judge' and context strongly influence any evaluation (section 5.3.4).

5.3.1 Was the objective and target achieved?

A way to judge whether a scenario study has been successful is to identify the original objective and target of the proponents or compilers. In principle scenarios studies address issues that are of central concern to a very wide audience, since the provision of adequate energy services is a prerequisite for human development. However the primary audience includes researchers, educators, policymakers in private and public sectors and other workers in the energy, technology, economics, and environmental areas.

Important lessons of scenario building exercises are not the single numbers but the relations between results and assumptions, the variations or the invariance across scenarios, time horizons and regions. The process of transforming the numerical results into conclusions requires finding result determinants (what piece of data causes the numerical results, flows of causality), evaluating the absolute and relative importance of the determinants (flows of values), assessing the possible range of the determinant input data.

Scenarios help identifying the effect of assumptions – technological developments, policies and events – but they do not suggest any policy, nor that some scenario is better than others, nor eventually how to achieve practically the future that is depicted. Scenarios / sensitivity runs have the function of exploring different possible future developments; they do not suggest any policy or prediction. Furthermore, the policies that can make a scenario happen are different from the analytical tools used to build a scenario with a model.

"Before accepting or rejecting the insights or suggestions that a model has to offer, a policy maker or policy adviser should ask some key questions about the exercise's assumptions [IEA/OECD, 1998]:

- Does it project reasonable rates of economic growth?
- Is it too optimistic or pessimistic? How and why does it assume that structural change (shifts in the relative weights of sectors with different energy intensities) will occur?
- Are the price and income elasticities of energy demand sensible and, if possible, based on at least some extant empirical research?
- Do assumptions about the cost and availability of technologies accord with prudent science and avoid utopian hopes?
- Finally, for estimates of mitigation costs, do the model's assumptions about market efficiency accord with reality?"

When scenarios aim at selling ideas or achieving political aims, the preparation phase is as important as the scenario implementation phase and the presentation of the main outcomes. The following conditions have to be ensured:

- Questions are clear – a model scenario primarily provides answers to questions; questions may rise indirectly;
- The appropriate modelling framework is used – different models must be used for answering different questions;
- The structure is flexible – the advantage of starting from models generator, instead of models;
- Results are transformed into answers – numerical results and output tables/graphs are not "the answer", analysts have to draw conclusions and statements from the numbers.

The following preconditions seem necessary to ensure that energy models and energy-environment scenario analyses contribute to policy decisions at some level (see also Annex C).

- The public is concerned by some 'dynamic phenomena' or rapidly changing patterns, whose evolution may reduce the utility to an unknown degree. Major examples are climate change, past oil crises, blackouts, local pollution problems.
- The government, central or local, has the political need to convert these concerns or fears into action; it prepares laws and has the need to implement something practical and visible.
- Important social, economic and political groups support action.
- A governmental authority or regulator has implementation and enforcement powers, and clear objectives.
- The regulatory body gives to analysts clear mandates.
- Analysts are/appear independent and analyses are validated by independent groups;
- Methodologies are scientifically consistent, transparent, reproducible, and conducted at a level appropriate to the objectives.
- Conclusions are formulated simply, explained in common terms, and make sense from several other points of view.

It has also to be considered that the "success" of a scenario depends also on the way it is used. The starting point is that in a democratic environment technical controversies cannot be avoided, as demonstrated by [Arrow, 1964]. If shared conclusions and practical decisions have to be drawn out of the scenarios, assuming a technocratic truth has not proved useful in the past. It proved to be successful the use of public debates or other social participation processes, and negotiations between interested parties. If scenarios are used as a tool for consensus building and shared decision making, the group that has modelled the energy system and implemented the scenario need the following attitudes [Meskens & Laes, 2003]:

- Truth telling: specify the nature of scenarios as different from forecasts, distinguish objective from subjective information, certainty from uncertainty and areas of irreducible ignorance.
- Systemic view: clarify what is inside from what is outside the system, what is considered from what is not, in space, time and logical terms.
- Transparency: give access to the input information declare the type of model and the underlying criteria; demonstrate that different inputs produce different results; phrase intuitive conclusion with appropriate and simple terminology, explained counterintuitive results.
- Openness to learning: connect the activity to earlier research or parallel effort and disciplines; acknowledge strong and weak points of the paradigm and limits of the approach; use descriptive language and avoid the prescriptive one.
- Fairness: allow a sufficiently large number of perspectives, by addressing representative numbers of technologies, impact categories, benefits (consumer, producer, including 'common goods' and 'social needs') and risks (social distribution burdens, intergenerational vs. intra-generational risks).

5.3.2 Does it portray a consistent view of the future?

The distinctive feature of scenarios in contrast with simple projections is consistency, internal and with reference to exogenous assumptions. Established modelling methods and rules are normally used to ensure that scenarios not only are consistent, but also reproducible and transparent. Simpler methods make all sort of consistency check easier. However, when the objective of the scenario exercise forces the use of more complex methods and more detailed analyses is twinned to simpler story lines built around inputs and outputs of the model. In every case the most relevant causality chains hidden in thousand equations has to be explained in simple words and intuitive cause-effect chains. Counter-intuitive results have to be clarified.

"Greater elaboration in formal modelling does not mean reduced scope for informal subjective judgement - indeed the opposite may be true." [Keepin and Wynne, 1984]. On this issue they are met by the [IIASA/WEC, 1981] study: "The models of the kind that we use here provide only a way of examining the consequences of the assumptions that are made. The use of numbers in these models is meant only to express qualitative features. In other words the numbers are intended solely as a means for expressing patterns. They are indicative, not accurate and exhaustive."

Sometimes [IIASA/WEC, 1981a, b] scenario studies attract enormous attention, primarily due to their degree of elaboration, which includes sophisticated models and computer work. But sometimes ([Keepin, 1984], [Wynne, 1984], [Thompson, 1984], and [Keepin and Wynne, 1984]) out of a huge body of input data and thousand of equations, only a handful of data and constraints determine most numerical scenario output.

Energy experts "operate under cultural concepts rationalizing different ways of life" [Thompson 1984]. "They may thus be working quite "objectively", including empirical measurement but within a fundamentally biased problem definition" [Wynne 1984]. For [Keepin and Wynne, 1984] as well as for [Sassin, 1980], scenarios "are not merely extrapolations of past trends. They contain an element of judgement, insofar as inconsistencies arising from conflicting trends have to be resolved. A strict distinction between "experts and laypersons" is not justified because both are not free of biases. However it seems more correct to address this fact as 'subjective aspects' of scenarios.

5.3.3 Did the quantitative projections happen to be true?

Energy modellers working in the aftermath of 1970s oil shocks expended enormous effort in projecting future energy trends. Because 2000 is a round number, it was routinely used as an end-point. The U.S. Department of Energy (DOE) looked back to energy projections to the year 2000 prepared before 1980. As shows, actual U.S. energy use in 2000, which is superimposed on the graph, was at the very lowest end of the forecasts. Energy use turned out to be lower than was considered plausible by almost every expert[36].

[36] except [Lovins, 1976, 1979], who anticipated perfectly total energy consumption in the year 2000 (not afterwards), but with shares completely different from actual ones.

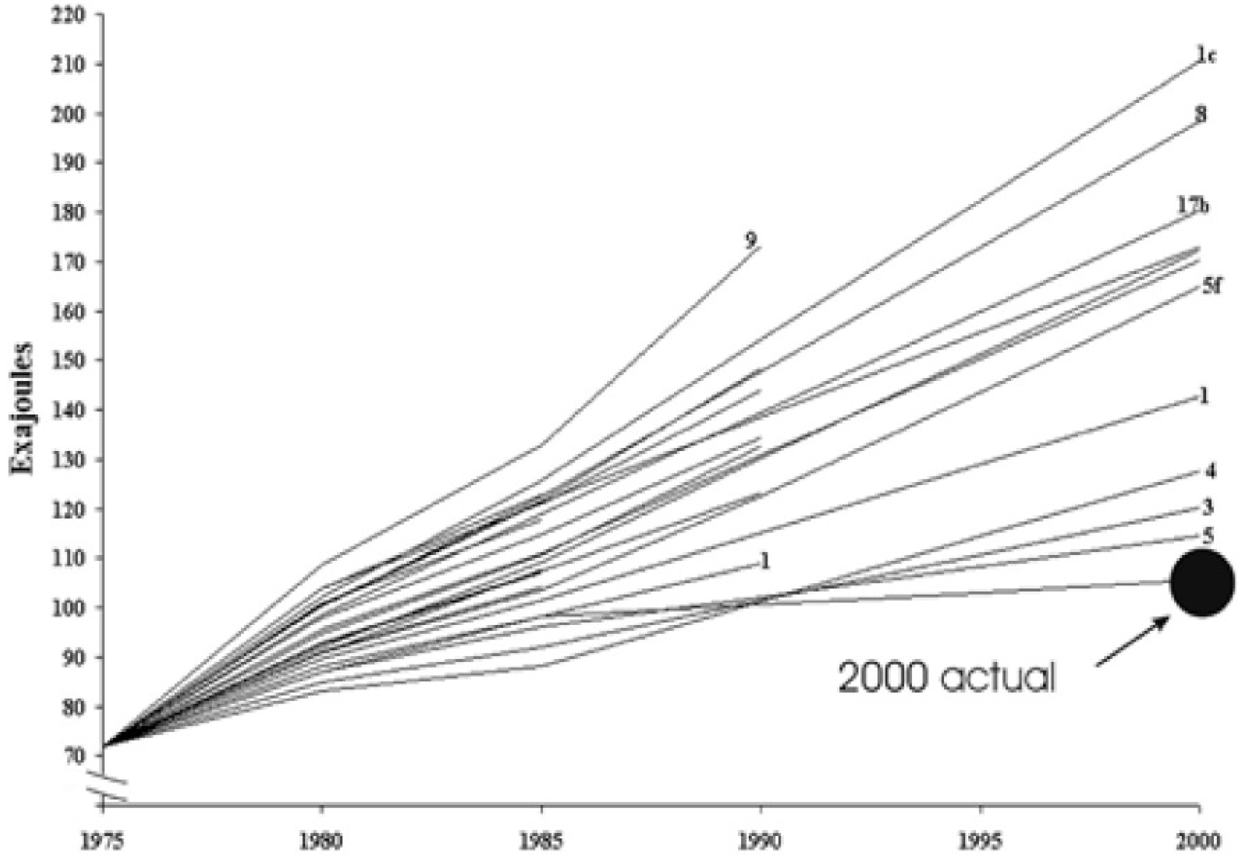

Figure 14: Projections of total U.S. primary energy use from the 1970s[37].

It is easy to criticize projections and scenarios after verifying that statistical values are different. In the very few cases when projections compiled 30 years before are close to statistical values, it is normally the result of wrong combination of wrong assumptions and wrong deductions. But the purpose of building scenarios is not to predict (say in advance) what will happen but to pave the way to more rational / robust decisions.

Perhaps the most interesting reason why a model might fail is that predicting problems can lead to changes that avoid them. In this sense failure would in fact indicate the success of the model. Much global climate change modelling has the goal of providing information intended to affect the future.

[37] The figure is redrawn from [US-DOE, 1979] and simplified from a summary of dozens of forecasts. Actual use at the end of the century [105 exajoules] is indicated. Apart from Lovins, forecasters clearly did not anticipate the ability of the economy to limit growth of energy use. Lovins' "soft energy paths" were designed to argue that a low-energy future for the United States was feasible. The approach posited a scenario based on the concept of unexplored options (the road not taken) and argued that we would be better off if we would take it. Lovins' qualitative numerical estimates of energy use were below those of almost all other forecasts and turned out to have been remarkably accurate. His goal was to make the case that technical advances would allow the nation to shift away from historic trends of an ever more fossil- and nuclear-based energy supply and toward renewable sources. His scenario hits energy use at the end of the twentieth century almost exactly. However, it shows energy use decreasing, whereas use in the United States actually increased by 1.7% per year, from 87 EJ in 1990 to 103 EJ in 2000. The original figure includes supply mixes, with a focus on renewable sources. The year-2000 scenario (and actual) supply mixes were oil/gas 26% (63%), coal 23% (22%), nuclear 0% (22%), and renewable 26% (7%).

5.3.4 How do energy experts perceive different scenarios?[38]

The technical quality of an analysis does not assure impact. Energy forecasts are carried out for a variety of reasons. They are commonly released in complex, sometimes sharply polarized, political environments with contending interests, sometimes with the ruling political mindset already made up. [Greenberger et al., 1983] reviewed 14 major energy studies undertaken in 1972--1982. They found 9 to be highly controversial and politicized in their execution, reception, or use (for study citations see [Greenberger et al., 1983]). The Ford Energy Policy project, initiated in 1972 and released in 1974, called forth plaudits as well as resentment and antagonism owing to its conclusions emphasizing the need for energy conservation to be driven by regulatory measures. The Energy Research and Development Administration (ERDA) was stunned by the criticism of its first report (ERDA-48) released in 1975, which slighted conservation options and adopted a supply focus.

In 1977, the year of the incoming Carter administration, the outgoing ERDA produced its most comprehensive study, the Market Oriented Program Planning Study. Unexpectedly to the ERDA, this study became the centre of a highly publicized conflict with the new administration over estimates of future gas supply. The classified CIA study completed in April 1977 on the international energy situation buttressed (fortuitously) the Carter administration's energy position so well that most of it was declassified with alacrity and released to the public with great publicity, developments that stunned the CIA's own analysts. The released study became controversial and was savagely attacked for tailoring its conclusions, yet the CIA analysts had no prior idea of the central role their report would be selected to play in supporting Carter's National Energy Plan.

Sometimes the media attention focuses on a misunderstood or dramatic (but possibly minor) aspect of a study and virtually ignores the more substantial conclusions. The media coverage of WAES (Workshop on Alternative Energy Strategies) report in May 1977 emphasized looming shortages without making a distinction between long-term supply/demand imbalances that could be managed by gradual market adaptation and short-term overnight shortages that would cause long lines at gas pumps. It was a major disappointment to WAES members, who regarded their study as "a call for action, not a cry of despair." Another WAES disappointment was the failure of the study to reach the highest levels of the government. Carter never invoked the WAES study to support his policies---he invoked the CIA study that had arrived at a more opportune time, one month earlier. The Ford-MITRE study garnered little media attention, but was highly influential, as some of the study's participants assumed important roles in the administration and put into effect some of the study's main recommendations.

Technical quality, attention, and impact are subjective evaluations for any energy study. However, it is possible to gauge a measure of these attributes by conducting surveys of energy experts to seek their assessments of selected energy forecasts. Greenberger et al. systematically surveyed close to 200 members of what they call the "energy elite" for their assessment of 14 energy studies from 1972--1980. They used an "attitude" survey of the experts to divide them according to their allegiance to one of the two core viewpoints. One group, labelled "traditionalist," was growth oriented, favoured nuclear power, believed in deregulation and the market's ability to efficiently allocate resources, and was sceptical about the near-term promise of solar energy. The other group, labelled "reformist," had great sensitivity to environmental concerns, favoured vigorous enforcement of environmental protection laws and promotion of a resource conserving ethic, and was troubled about the implications of today's energy decisions for future generations. This group opposed primary reliance on nuclear power and favoured greater emphasis on renewable sources such as solar and biomass.

Each participant was asked to rate each study from the perspective of analytical strength, attention (from the media), and impact, assigning letter grades from A (highest) to E (lowest). Grades from within each group were averaged. As one would expect, the assessments are distinctly different across the two groups. Table 7 summarizes the survey results for 12 energy futures studies.

[38] Text quoted from [Craig et al., 2002]

Table 7: Assessment of 12 energy futures studies from the 1970s by two groups of energy experts with different viewpoints about renewable and traditional energy systems [Greenburger et al., 1983]

Study	Quality[a]		Attention[a]		Influence[a]	
	Trad.	Refor.	Trad.	Refor.	Trad.	Refor.
Ford Energy Policy Project	D	A-	A	B	A	A-
Project Independence Report	C	E	B	B	C	D
ERDA-48 and ERDA 76-1	D	E	D	C	D	D
MOPPS	C	D	D	D	E	E
Ford-MITRE Study	B	B	C	D	A	A-
Lovins "soft paths"	E	A-	A	A	A	A-
WAES Study	C	B	C	C	C	B
CIA assessment of int'l energy	C	B	B	B	B	A
CONAES	B	C	C	C	D	D
Stobaugh and Yergin	D	A	A	A	A	A
RFF-Mellon Study	A	B-	D	D	D	E
Ford-RFF Study	A	A	D	D	D	C

a) Participants assigned letter grades to each study, from A (highest) to E (lowest). Trad., traditionalist group; Refor., reformist group; ERDA, Energy Research and Development Administration; MOPPS, Market Oriented Program Planning Study; MITRE Corporation; WAES , Workshop on Alternative Energy Strategies ; CONAES, National Academy of Sciences Committee on Nuclear and Alternative Energy Strategies; RFF, Resources for the Future

One major theme that emerges from this study is that the interviewees' assessments differed enormously regarding quality and influence, and that there was little correlation between the two. The survey authors observed that "studies generally regarded high in quality tend to be non-controversial and integrative in nature. In reflecting ideas already known and accepted, they are not as likely to attract attention and exert influence (other things being equal) as studies with striking and fiery conclusions". Another theme is that the assessment of analytical strength is correlated with the views of the reviewers. The Lovins, Ford Energy Policy Project, and Stobaugh and Yergin studies show the extremes most clearly. Both found favour with reviewers favouring renewable sources, whereas analysts who preferred traditional energy systems such as coal and nuclear power found them technically flawed.

Views on study quality were influenced by points of view. [Greenberg et al., 1983] found that energy policy analysts and policymakers who favoured nuclear power (traditionalists) disliked both the methodology and the conclusions of the analysts who argued for the feasibility of demand reduction. Those characterized by Greenberger et al. as reformists were equally critical of the analysis of the traditionalists[39].

In this field, it is important to be aware that detailed overviews of scenarios over time enable to record changes in perception over time[40]. Furthermore people, as well as scientist have personal and social cultural

[39] Little has changed in the intervening quarter century. Precisely the same split over precisely the same issues is occurring today (2002) in the debate over the Bush Administration energy program.
[40] A detailed overview is provided for instance in the UNDP-report (United Nations Development Programme of Goldemberg and Johansson (1995), Goldemberg et al. (1995), Ygdrassil (1989b) Forum f. Zukunftsenergien (1997), Keepin et al. (1986). Each of these publications covers a part of the great variety of scenario studies. The most important ones, however, are the following:

values. Confronted with the Royal Society and the US National Academy of Science statement that if the present demographic projections will turn out true and human activities on earth will not experience structural changes, science and technology could not be able to hinder the irreversible deterioration of the environment nor to prevent a future of poverty to a significant part of the world, pessimists will worry, optimists will accuse scientists to look for easy publicity.

5.4 Lesson learnt by energy scenario developers[41]

Document Assumptions

The importance of clear and complete documentation to successful forecasting and scenario design cannot be overestimated. Instead of burying analytical assumptions and value judgments in "black box" models, as is so often done, it is essential that all assumptions be recorded in a form that can be evaluated, reproduced, and

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- The World Energy Council (WEC), which organizes the periodic World Energy Conference (WEC) and provides detailed and scenarios, is included in the present study with two publications (WEC 1983, WEC 1993). The joint studies of the International Institute for Applied Systems Analysis (IIASA) and WEC (IIASA/ WEC 1981a,b and 1995), which are produced by the well-respected IIASA energy systems group (now ECS = Environmental Compatible Energy Strategies), are also among the "classical" scenario studies.
- Shell International Petroleum Company seems to be an excellent example for a private, commercial organization that has expressed interest in studies on present and future energy supply. One of their two scenarios, the so-called "sustained growth" scenario, projects a world energy consumption level of about 50 TW for the year 2100 (Shell 1995). Based on our findings this was the highest energy consumption level ever assumed in a scenario.

Other important studies were published by the United Nations (e.g. IPCC = Intergovernmental Panel on Climate Change and RSWG = Response Strategies Working Group). This includes the 1990 and the 1992 scenarios (IPCC 1992), the RSWG results (IPCC 1990) and several bottom up and top down LESS or LEESS (Low CO2 emitting energy supply system) constructions (IPCC 1996a, Edmonds 1994). The RIGES (Renewable Intensive Global Energy Scenario) (Johansson et al., 1993c) was prepared as an input for the United Nations Conference on Environment and Development (UNCED) held in Rio de Janeiro in 1992. The publication "Energy for a Sustainable World" (Goldemberg et al. 1988) appeared to be the first dealing with sustainability. French scientists produced a NOÈ (Nouvelles options énergétiques) - transformed to NOES (New options on Energy Supply) - with assumptions of a high increase in efficiency (Dessus, 1996). A Solar-Fossil High- Efficiency Scenario was produced by the German research community for air and space flight DLR, (Deutsche Forschungsgesellschaft für Luft- und Raumfahrt), (Langniß et al. 1997, Forum f. Zukunftsenergien 1997). Lovins and Lovins (1982) produced a scenario that marked the lower boundary of the projections, with 5 TW global energy consumption for the year 2030, seems to be an optimistic target (Goldemberg et al. 1985). The OCF (Our Common Future = Brundtland Report) scenarios (Duchin and Lange 1994) addressed the issue of sustained economic growth without harming the environment through a detailed evaluation of the approach outlined in the "Brundtland Report" (WCED 1987). Edmonds and Reilly (1985) as well as Nordhaus and Yohe (1983) also produced emission scenarios that are commonly cited and had a range up to the year 2100. Another peculiar distinction was presented by Anderberg (1996): the "surprise-rich" scenarios based on a workshop in Sweden, which was hosted by IIASA and the Swedish Council for Planning and Coordination of Research In addition, a wealth of studies and papers does not present scenarios in a narrow sense, but rather describes future developments of global or regional energy parameters (see).

The investigated scenario studies revealed the following results:

- There is a great range of different end-times and levels of reached world energy consumption.
- There is a great range of total consumption as well as roles and shares of different energy carriers.
- One population growth assumption is chosen as an input constant. Although this method exerts a great influence, this appeared to be necessary in order to simplify the model.
- Nearly all scenarios are based on increasing primary energy consumption levels. The only exception we found was the "efficiency scenario" of Lovins et al. (1981), with a global rate of energy consumption of about 5 Terawatt for the year 2030. The above-mentioned rise takes place even in studies that assume an extreme increase in efficiency; this is rooted in the dynamics of a population development and economic growth based on an expanding primary production industry, as is expected to exist in developing countries striving to meet their needs in moving up.
- Use of fossil fuels will continue, no major resource constraints are expected for the next century.

[41] Quoted from [Craig et al., 1983]

used by others. The uncertainties in predicting the future are vast, and making assumptions for the most uncertain variables is often the best we can do. Unless those assumptions are explicit, however, others can't evaluate their reasonableness, and one can't credibly claim to be doing anything akin to science. It is for this reason that simpler and more transparent models are often superior in accuracy and usefulness to large and complex ones, because the simpler models are more amenable to peer review of underlying data and assumptions.

Documentation and simple explanations lend credibility to any intellectual effort. They also acknowledge the previous work of others and allow readers to follow thought processes (they also allow authors to recreate their thinking months after they have achieved some conceptual breakthrough). Any competent analyst ought to be able to recreate an analysis from the documentation provided, and the original author should be able to do the same more quickly than others can. Finally, the process of documenting one's results can help one check those results and ensure accuracy.

The importance of transparency of models cannot be overestimated. A model that the audience can actually grasp is inherently more persuasive than a "black box" that no one outside of a small circle of analysts understands. Transparent models for which the input data and assumptions are also well documented are even more compelling but are, sadly, all too rare.

Link the Model Design to the Decision at Hand

Thousands of person-hours are wasted each year because people asking for forecasts have no clear idea of what decision they are trying to influence or who will make that decision. No forecasting exercise should be undertaken without clearly defining the audience and the decision they will be called upon to make. What decisions are being considered? Who will make them, and when? Answering these questions can allow for more effective use of forecasting resources.

Beware of Obsession with Technical Sophistication

Accurate data compilation and careful scenario creation are more important to achieving forecasting success than are complex programming or esoteric mathematics. As discussed above, there is no evidence that more complex models are any more accurate in forecasting the future than are simpler models.

Simple and transparent models, properly used, can be immensely powerful. Analysts at the International Institute for Applied Systems Analysis (IIASA) found this out to their chagrin when Will Keepin, a visiting scholar at IIASA, was able to almost exactly reproduce the results of a multiyear, multimillion dollar study using some of the study's key input assumptions and a hand calculator. Keepin showed that the study's results followed directly from the input assumptions. He concluded that the study's projections of future energy supply "are opinion, rather than credible scientific analysis, and they therefore cannot be relied upon by policy makers seeking a genuine understanding of the energy choices for tomorrow."

Beware of big complicated models and the results they produce. Generally they involve so much work to keep them current that not enough time is spent on data compilation and scenario analysis. Morgan & Henrion, in their book Uncertainty, devoted an entire chapter to such models and began by summarizing this fundamental truth: "There are some models, especially some science and engineering models that are large or complex because they need to be. But many more are large or complex because their authors gave too little thought to why and how they were being built and how they would be used." Such large models are essential only for the most complex and esoteric analyses, and a simpler model will usually serve as well (and be more understandable to your intended audience).

Do not be too impressed by a model's complexity. Instead, ask about the data and assumptions used to create scenarios. Focus on the coherence of the scenarios and their relevance to your decisions, and ignore the marketing doublespeak of those whose obsession with tools outweighs their concern with useful results.

Watch Out for Discontinuities and Irreversibility

One of the biggest unsolved issues in forecasting relates to the treatment of discontinuities. In the analysis of climate change, for example, many climate models assume linear responses to perturbations in greenhouse gas concentrations. Unfortunately, there is an unknown nonzero probability that the climate system may respond in a discontinuous manner to rapid changes in greenhouse gas concentrations. For example, there may be thresholds beyond which the climate "snaps" to a new equilibrium level that is far from the current one, which could include substantially different ocean circulation and temperature patterns. Such discontinuities are inherently difficult or impossible to predict, but they remain important to consider, particularly when they might lead to large, irreversible, or catastrophic impacts.

Do Not Assume Fixed Laws of Human Behaviour

A common failing afflicting even sophisticated analysts is that they seek immutable laws of human behaviour, much as the physicist discovers physical laws through experiment. Such generalizations about human and economic systems often fail because these systems are adaptable in ways that physical systems are not. Policy choices affect how the future unfolds, and parameters that embody historical behaviour are bound to lead us astray whenever a forecast relies on those parameters to forecast far into the future. Assuming that human behaviour is immutable will inevitably lead to errors in forecasting, no matter which kind of modelling exercise you undertake.

Modellers often create forecasts assuming that key input parameters will be similar to their historical values, even when exploring futures that are unlike anything that have ever happened before. This error is particularly egregious for forecasts that look many decades ahead, and can lead to colossal errors.

Most economic forecasting models embody historical experience through relationships that are derived statistically and then use those relationships to forecast the future. These models are often used to assess the potential effects of proposed changes in government policy or business strategy. The fact that these models embody history does not mean they can give an accurate picture of a world in which the fundamental relationships upon which they depend are in flux.

At a minimum, if the statistically derived relationships embedded in such a model are the very ones that would be affected by choices or events, then those relationships must be modified in the analysis. For example, after the OAPEC embargo of 1973 energy efficiency became important; energy growth and electricity growth rates dropped dramatically. Forecasts that assumed continuance of historic relations between economic and energy growth were grossly wrong. If society decides that climate change is sufficiently threatening that large-scale preventive action is required, such action will represent a similarly large change in historical patterns.

Many prominent forecasters continue to fall prey to the pitfalls described above. The world in which policies and technologies are adopted is one governed by increasing returns to scale, institutional change, and path dependence. Forecasts that do not account for the dynamic nature of human behavior and technology adoption in characterizing these effects are bound to miss the mark.

Use Scenarios

If forecasts are part of your planning process, do not rely on only one. Use a set of forecasts or scenarios to explore the future. Schwartz's examples of scenario analysis typically have only a small quantitative component, but many other futurists err by focusing too much on the mechanics of forecasting and quantitative analysis (e.g., on particular modelling tools and techniques) and far too little on careful scenario development. Quantitative analysis can lend coherence and credence to scenario exercises by elaborating on consequences of future events, but modelling tools should support that process and not drive it.

In the face of inevitably imperfect forecasts, the most important way to create robust conclusions is to create many well-considered scenarios. No credible analysis should rely on just one or two forecasts. It is also important to look at projections undertaken by different groups, using a variety of techniques, and funded by organizations with different goals.

Vary key factors, and investigate which of them to ignore and which to dissect further. All forecasts are wrong in some respect, but if the process of designing them teaches you something about the world and how events may unfold, creating them will have been worth the effort.

Use Combined Approaches

In his analysis of the accuracy of time-series techniques by electric utility load forecasters, Huss concludes, "combination forecasts seemed to outperform all other time series techniques tested. These techniques seem to be able to take advantage of the best characteristics of all techniques which comprise the combination." Combining different approaches allows biases in one technique to offset biases in other techniques.

Expect the Unexpected and Design for Uncertainty

Naturally, questions arise about the risks of misjudgements and errors resulting from forecasts and how to manage these risks. One approach is to identify and adopt strategies that are robust in the face of the inevitably imperfect and uncertain forecasts. For example, several computer companies have moved to "build-to-order" manufacturing, which allows them to assemble computers as requested by customers. This strategy reduces dependence on forecasts but introduces other challenges in manufacturing (which are surmountable using current technology). This same lesson applies equally well to other such decisions: If the key variables are difficult or impossible to foresee, then use scenario analysis to evaluate the possible outcomes, assess the situation from multiple perspectives, analyze the uncertainties using statistical techniques and formal risk assessment where appropriate, and adopt strategies that are less dependent on forecasts. Also consider using concepts like the precautionary principle as risk minimization tools.

Communicate Effectively

Forecasts can be technically strong but can fail to influence their target audience because of poor communication of the results. Conversely, a forecast that is not technically sophisticated but that is communicated effectively can sometimes be influential in spite of its inherent weaknesses. A forecast that is successful for one group may be a total failure for another. The way in which the results are framed can be enormously important to a study's credibility and influence.

[Greenberger et al., 1983] note that over time some studies that were initially highly controversial for both technical and policy reasons became more widely accepted. An example is the Ford Energy Policy Project, about which Greenberger et al. wrote, "Its heresy became the new orthodoxy within four years." Not surprisingly, these changes did not come about passively. The authors of these studies engaged in vigorous and effectively communicated defence of their findings. A similar observation applies to Lovins' early soft path analysis. Lovins' prolific, effectively communicated, and highly documented defence of his study is contained in the proceedings of a U.S. Congressional hearing (which also included attacks on his views).

When creating a forecast leaves enough time to craft an effective summary of the results in a form that your intended audience will find compelling. The time spent will pay off in greater influence in policy debates.

Be Modest

We need to be humble in the face of our modest abilities to foresee the future. This caution is especially warranted when assessing effects of technological choices on the environment, as discussed above, but it applies equally well to most energy forecasts. Fundamental limitations on our ability to foresee consequences have important implications for the ways we use forecasts in our planning.

Reading some old writings is both instructive and humbling. We have already noted Jevons' book exploring the prospect of England's running out of coal. In 1893 The World Columbian Exposition was held to celebrate the technological prowess of the time. Great thinkers of the day were asked to prognosticate about the next hundred years and were consistently off the mark. George Westinghouse, founder of Westinghouse and inventor of the modern compressed air train brake, wrote that trains were unlikely ever to go faster than 30 miles per hour. He saw this as no problem, however, because there was no need to go faster.

A century ago, H.G. Wells departed from his traditional science fiction writing and wrote a book expressing his personal views as to how the world might unfold during the twentieth century. He thought aircraft might have a marginal role by the end of the twentieth century, thereby totally overlooking the role they were to play in World War I, only a dozen years ahead. However, he foresaw with unbelievable prescience the coming of freeways and the age of the automobile.

5.5 Annex B: suggestions for building contrasted EFDA-SERF scenarios

The global multi-regional EFDA TIMES energy model seems a very good tool to explore contrasted futures till 2100. Keeping in mind the great interest of fusion research communities to show that the fusion technology can have a market in 2100, it seem important to devote some resources to the development of innovative methods and tools to build long-term energy – environment scenarios. Other research could improve the tools capable of modelling together the three dimensions of technological detail, micro-economic realism and macro-economic completeness.

Other tasks could build and analyse scenarios as contrasted as the following four story lines. None of them can be properly addressed as reference, but each of them includes valuable although contrasting insights. This would follow the approach of the Special Report on Emission Scenarios of the Intergovernmental Pane for Climate Change [IPCC SRES, 2000] and could avoid that only the reference scenario is quoted outside the project.

5.5.1 Policy path

An adverse international mood and fierce global economic competition makes more aggressive mitigation policies hard to propose. In Europe present policies are maintained but they are not very successful, due to lack of innovation and low public consensus. From the modelling point of view, this scenario is built with the techniques of Business As Usual. It may be thought as a reference scenario, although it is not more likely than the other ones.

5.5.2 Technological (innovation) path

International cooperation and a great RD&D effort brings to use very efficient end use technologies (e.g.: …) and finds cheaper ways to harness where available and dispatch where demanded renewable forms of energy. Therefore the growing demand for energy services worldwide decouples to a great extent from the supply of primary of primary energy and the GHG emissions related to the supply of primary energy greatly reduce. Higher investments in research and even more in deployment increase the overall energy efficiency of the system much more than it has been measured by the autonomous energy efficiency improvement (AEEI) in the past decades. Long-term planning and efficient regulations increase smoothly and regularly final energy prices and convince the final users to invest in 'energy efficiency' over and beyond the present levels. The large social consensus, which is implied in this scenario, is not problematic, because the new technologies are by far preferable to the existing ones (for instance, as it has been in the past the transition from carts to cars, or from oil to electric lamps). Since the transition to new technologies is global, emissions reduce globally and the GHG concentration stabilise at 450 ppm. The global as well as the European economic growth is strong because GDP is growingly composed of the value added by new technologies than by traditional resources and branches.

In the model strong technology improvement and wider deployment are included in the standard technology database as additional options. They are included either with some form of Endogenous Technology Learning or with exogenous cost reductions, efficiency improvements and earlier availability; the most efficient existing technologies are given greater shares and market possibilities. Although the price of coal oil & gas remain rather low, final energy prices remain considerably high because they reflect the higher added value of new technologies.

5.5.3 Social (value change) path

The international economy is not particularly favourable to energy innovation, neither in the research nor in the deployment phase. The market offers limited choices of new efficient energy technologies, which cannot enter the market by purely economic grounds. Faced by big indifference in other world regions and delays in deciding mitigation policies, Europe and possibly other regions continue efforts to curb its own emissions. It enforces a complex and diversified set of policies in all the most relevant supply and demand sectors. These policies include:

- Internalization of traditional local and regional externalities,
- Consumer taxes, and
- Temporary subsidies for technology learning and cost reductions down the experience curves.

Public debates and social participation make it possible to redirect consumers' utility to less energy intensive demands, to deploy all no/low cost mitigation options and to use locally all available energy sources also in cases where their costs are slightly over the equivalent international energy prices. This is promoted – also with incentives – and accepted as an insurance against fluctuating prices and over-dependence from uncertain suppliers. This scenario is compatible with stabilization at 550-650 ppm, but with a lower economic growth in more advanced regions. In the model, the standard technology database, intermediate economic projections and energy service demands are used. Both primary and final energy prices remain high over the time horizon.

5.5.4 Surprise path (exogenous discontinuity)[42]

Strong economic growth mainly in traditional sectors strains global markets of energy and energy intensive commodities. The deep international divide on climate change, both on responsibilities and mitigation policies, increases the rate of GHG emissions and concentration growth. The use of energy infrastructures to their capacity limits makes price high and fluctuating; the supply remains insecure globally and locally. Particularly in newly developed countries consumers continue the trend of 'big is better' and demand increasing amount of energy services. This reflects in even higher pressure on supply because energy efficiency does not improve at a satisfactory level. Investments in traditional supply options outgrow investments in new supply technologies and even more in new efficient demand devices.

The international trend towards the highest economic growth and the increasing competition of producers worldwide bring most government to gradually reducing every 'environmental barrier' to competitiveness. On the contrary, in order to ensure some economic growth, incentives to production override environmental

[42] The "Seven Tomorrows" set of scenarios was a product of the futures group at SRI International. Seven futures were described in story form, and each was fleshed out with numerical estimates for key variables (energy, GNP, population, etc.). The authors were well aware that events they could not plausibly foresee might upset all their intellectually defensible scenarios. They addressed this inevitable shortcoming by including an implausible scenario, "apocalyptic transformation, in which a remarkable individual emerged in the American West preaching a gospel of low impact values. His message resonated, and the structure of the nation changed." This type of thinking can broaden views and may help the next generation of forecasters avoid the kinds of embarrassments caused by some past scenarios.

regulation to 'where/when possible'. The economic support to production and the need to fight for energy resources reduces investments in energy research and technologies.

After 2030, conflicts over energy resources, energy supply disruptions, food and water shortages due to irregular energy supply and international trade deliveries, sharp income reduction in some regions, climate related events, etc., drastically reduce the demand after 2030 (say to 60-70% of 2030). This may result from GDP per capita reductions or even population crises[43]. In the model, the standard technology database is used together with energy service demands driven by ad hoc exogenous macro-economic developments and primary supply prices. Probably technology improvement disappears, new technologies are not competitive, average unit efficiencies go down, unit emissions increase, although total emissions reduce.

5.5.5 Questions for selecting new scenarios

- Do they explore the widest possible space of future events with a limited number of scenarios?
- Do they maximise the benefits of using in an integrated way the two main methodologies of SERF: the technological economic modelling approach and the social dimension?
- Do they catch the attention of social stakeholders and the general public?
- Do they raise the attention of the experts? Is it likely that other professionals adopt, approve, discuss, disprove or confute them?
- Do they attract other stakeholders (environment, coal, fission, oil&gas, renewables, etc.) to using the same tools and cooperating in building common / contrasted scenarios?

[43] Rational thinking cannot exclude global collapses, similar to the local ones recorded by history [Diamond, 2005].

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7 *Annex C: Did energy models improve policy decisions in the past?*

(Presentation to the 'Global Energy Models' WS organised by IPP, held in Garching in July 10-11, 2006)

Workshop Goal

Expectations about future developments, if not produced by a prophetic view, are always based on a model. These models might just consist of a very simple rule or a rather complex mathematical articulated structure, or just to toss a coin. The interaction between expectations and real development are rather complex, expectations might be understood as a warning and stop an expected development or in contrary lead to a self-fulfilling prophecy. The interaction between expectation and development is usually not part of the mental model producing the expectation.

Expectations about the development of the global energy system were already developed in the second half of the 19th century. "The coal question" of John Jevons is a prominent example. Certainly with the beginning of the 1970 and in the overall debate of resource scarcity and environmental problems, global energy models were developed and played an important role in the political debate.

The goal of the workshop is 1.) to review the questions which were addressed in the past by global models and the impacts these models had and 2) what questions needs to be addresses in the future and how the impact can be improved by addressing the relevant questions.

The goal of the workshop is not to have an extensive discussion of methodologies; the goal is to understand the interaction between pictures produces by energy models and actual political or economic decisions.

10th of July

11:00 A. Bradshaw, Welcome
11:15 T. Hamacher, Introduction to the workshop
12:00 LUNCH
13:30 J. Edmonds, JGCRI, The role of global energy models as basis for policy definition in the US
14:30 N.N., BP, What is the basis for strategic decisions in a global energy company?
15:30 Coffee
16:00 G.C. Tosato, Did energy models improve policy decisions in the energy field in the past?
17:00 Hake, FZJ, Sustainability and climate change: how can long-term issues impact everyday political decisions?
17:00 Discussion
18:00 Visit to the IPP
19:00 Dinner

11th of July

9:00 R.P. Shukla, IIMA, Rationality of Indian energy politics
10:00 N.N., WEC, Impacts of the WEC/IIASA studies on global energy politics
11:00 Harig, Former CEO Eon, Which information is necessary for an top-executive to make the right company decisions?
12:00 Lunch
13:00 Final Discussion
15:00 End of the workshop