IEA OECD ETSAP

International Energy Agency
Implementing Agreement for a
Programme of Energy Technology Systems Analysis

Global Energy Systems and Common Analyses

Final Report of Annex X (2005-2008)

Highlights and Summary

June 2008

Editors:
Gary Goldstein and GianCarlo Tosato

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Acknowledgments

The ETSAP partnership and the extended network of ETSAP tool users celebrated its 30th anniversary in 2008. The success of this nearly unique collaboration community can be attributed to the contributions of the 17 Contracting Parties, the dedication of the experts involved in ETSAP, and the efforts of the modelling community experts.

This report summarizes the advancements, applications, and accomplishments within the community and thereby demonstrates why ETSAP has sustained now for three decades. It provides many examples of policy relevant application of the MARKAL/TIMES modelling platform and its continued spread to new users through capacity building projects, as well as the ongoing advancement of the methodology to meet the requirements for integrated energy planning in these challenging times. With the knowledge and skills needed to effectively use the methodology now widespread around the world, the framework is positioned to make further important contributions towards identifying policies and pathways that will lead to the low-carbon future essential for sustainable development on our planet.

The editors wish to thank all those actively involved in ETSAP as well as those working with the ETSAP Tools who have contributed to this amalgamation of the accomplishments of the last three years. We also want acknowledge the assistance of Jerome LaMontagne and Kris Humbert towards ensuring the overall quality of this document.

Tribute to the Memory of Alan Manne

A special acknowledgement is given to the memory of Professor Alan Manne, whose pioneering efforts and substantial contributions to the world of energy planning and modelling are widely recognized. His legacy was spawned after graduating from Harvard by his groundbreaking work in operations research at the Rand Corporation. He is recognized as the "father" of the practice employing optimization techniques for energy/economic/environmental system modelling. His contribution to the development of MARKAL-MACRO has been essential. He is best known for his long association with the Stanford Department of Operations Research. He wrote seven books and more than 120 papers, and guided dozens of doctoral students and researchers from around the world. He was a co-founder of the International Energy Workshop which he then co-stewarded for 24 years.

You are referred to the San Francisco Chronicle obituary and Spring 2005 articles for additional information

http://www.sfgate.com/cgi-bin/article.cgi?f=/c/a/2005/09/29/BAGK2EVMDP1.DTL

and

http://sfgate.com/cgi-bin/article.cgi?file=/c/a/2005/06/03/PNGPGCUNPD1.DTL

Alan was a great inspiration, mentor and friend to many. Those who got to know him are well aware of what a very special individual he was, and how lucky they were to have had him touch their lives. His presence will be greatly missed, though not forgotten.

Highlights

This report presents the main results of collaborative, national and group activities of ETSAP partners and others using the ETSAP tools during the period 2005-2008, with special focus on scenario studies and policy evaluations, and the advancement of the methods employed. Those who would be interested in the accomplishments of ETSAP include:

- The IEA CERT representatives, particularly from representing countries currently participating in ETSAP, along with those who have expressed interest in joining ETSAP;
- The government sponsors of the various institutions involved directly in ETSAP, and those trying to become ETSAP institutions;
- Individuals engaged in the review and consideration of methodologies involved in the IPCC process, particularly those of Working Group 3;
- Parties to other IEA Implementing Agreements;
- The wider energy and Global Climate Change (GCC) policy community;
- MARKAL/TIMES modellers around the world;
- Other (GCC) researchers and modellers, and
- University professors and their students interested in growing programs that may employ the ETSAP Tools to groom the new generation of experts.

During the course of this Annex the Implementing Agreement for a Programme of Energy Technology Systems Analysis of the International Energy Agency demonstrated the relevant nature of the analyses carried out by the ETSAP Partners and community of users of the ETSAP Tools, while evolving in several important directions.

(a) (a) Use of the MARKAL-TIMES model enabled expert groups conducting integrated energy systems to reach new targets in quality, scope and numbers. United States, Germany, the United Kingdom, the Netherlands, Belgium, Sweden, Finland, Italy, Switzerland, and India, have issued major studies that have helped shape policy in their countries. New groups have formed in countries that are considering joining ETSAP (e.g. France, Portugal, Spain, Austria, and Norway). In addition, extremely competent teams have been established and expanded in the leading Plus-5 developing countries (South Africa, China, and India), while key countries such as Russia have also turned to the ETSAP Tools. As a result of ongoing training and internationally financed capacity building activities new groups are being established in other countries, such as Kazakhstan, the Balkan countries, and various ASEAN countries.

(b) In response to the G8 Gleneagles Plan of Action, the IEA developed the global MARKAL model, which was used to support analysis for the Energy Technology Perspectives (ETP) project in 2006/8. ETP focuses on the identification of technology pathways for achieving common IEA goals related to energy security, promotion of clean energy, and climate change.

(c) The original tools developed by ETSAP continue to improve. **T**he **I**ntegrated **M**ARKAL **E**FOM **S**ystem (the TIMES model generator), an advanced successor to MARKAL, is now mature and in full production use. Two users' interface (VEDA) and (ANSWER) fully support both models generators (MARKAL and TIMES), overseeing all aspects of working with the models. The underlying strength of the technical-economic partial equilibrium paradigm, complimented by the ease-of-use of the interfaces, are the primary reasons for the heightened interest and thereby growing user community.

(d) Dozens of energy models have been built with ETSAP tools, at the global, regional, national and local scale. Some are huge multi-regional global models, such as the IEA-ETP MARKAL model and the TIMES Integrated Assessment Model (ETSAP-TIAM), others are even larger regional models such as the thirty region Pan European TIMES model (27 member states plus Norway, Switzerland and Iceland) and the US multi-regional MARKAL model. However, single-country energy and environmental analysis remains the predominant use of the model. This allows for sufficient detail to fully represent the particulars of one particular underlying energy system.

(e) The models are being used to examine various aspects of the energy, economy, and environment nexus. The IEA studies the potential role that new technologies must play if we are to change the present energy systems in order to create climate benign, economically sustainable and secure energy systems by 2050. Important EC funded research projects make use of ETSAP tools, gather multi-national teams, build multi-regional models and analyse energy related policies, as exemplified by the New Energy Externalities Development for Sustainability (NEEDS) undertaking. The Energy Modelling Forum researchers are examining robust transition policies towards climate sustainable systems after 2100 using ETSAP-TIAM. Several groups use global, multi-regional and national models to explore the impact of different post-Kyoto regimes. Pan European and member states' models are used to identify the least expensive combination of measures that satisfy the demanding EC targets for 2020. And the more local models are also being used to study linkages been effective GCC and local pollution reduction strategies.

Synergies achieved as a result of advanced methodology, tools and applications have raised the importance of ETSAP and its mission. The IEA ETP2006+2008 publications have a wide diffusion (more than 2,000 copies) and advise the decision-makers of the G8 on climate change mitigation issues. The results of ETSAP-TIAM studies are being included among the groups that assess climate mitigation policies through EMF and IPCC. The expert groups using the ETSAP Tools that work for the Ministries in various countries are informing decision-makers on the merits and impacts of different measures for achieving the increasingly essential objectives of the energy security, climate change mitigation, and economic affordability in response to national policies and measures.

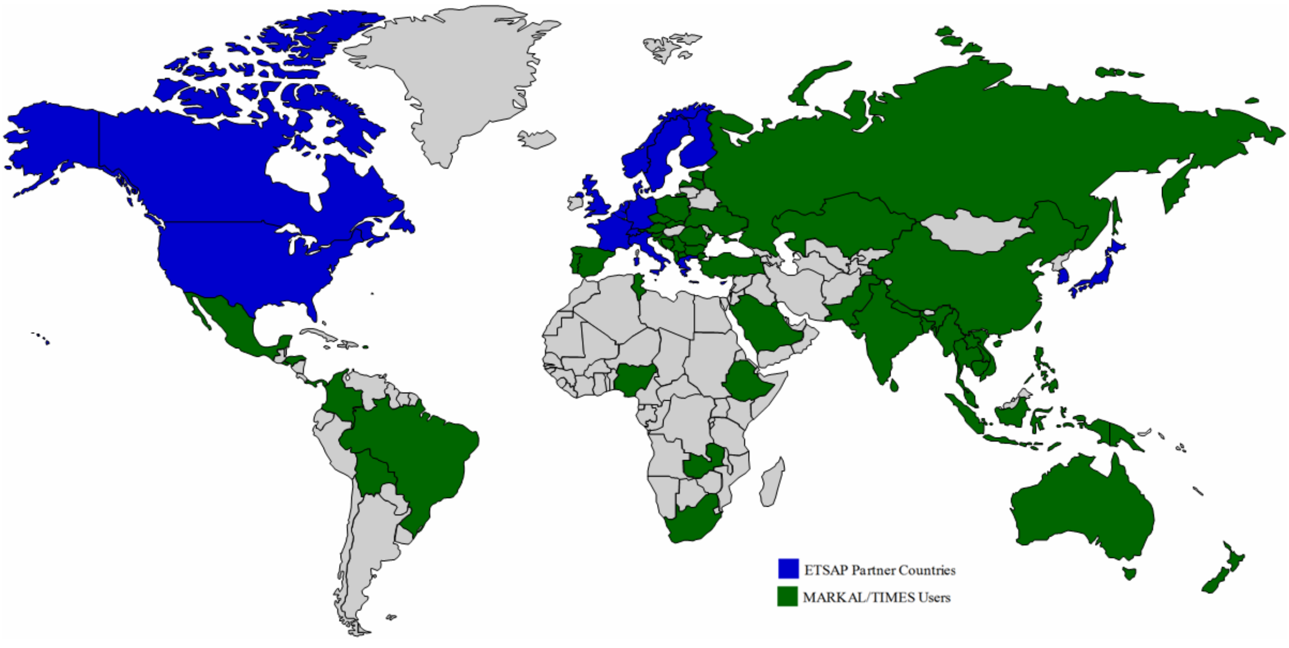
The cooperation activities of ETSAP are financed by the contracting parties (shown in blue in Figure H-1) at a level of about two hundred thousand euros per annum. This has been used mainly to leverage from international and national research institutions and collaboration to reach the [much higher] funding level needed to carry out the activities illustrated in what follows.

By the end of the Annex X there are more than 230 MARKAL-TIMES licensed institutions, of which nearly 180 are active in 69 countries (see figure H-1). Interest in ETSAP was reflected by participation in the biannual workshops where the number of attendees ranged between fifty and one hundred experts, giving between twenty and fifty presentations per workshop. Another indication of the relevance of ETSAP community is reflected by the number of articles that appeared in the scientific literature which increased from 6 during the 1998-2002 period to an average of 14 papers per year during the 2002-2007 period.

The full report illustrates all aspects of this growth by referencing the original reports, studies, papers and presentations where more details can be found.

This report underscores the increasingly dynamic and important contribution of the ETSAP community in providing state-of-the-art analytical tools and studies, leading to a greater understanding of the possibilities for meeting the critical energy and environmental challenges of this century.

Figure H-1: ETSAP Partners and the Dissemination and Use of the ETSAP Tools[1]



[1] Only those countries with at least one MARKAL/TIMES modelling team active during the Annex are "painted."

Contents

1. Summary of Annex Activities[2]

1.1 Objectives and Strategy

The Contracting Parties of this Implementing Agreement carry out a Programme consisting of co-operative Energy Technology Systems Analysis (ETSAP) [3]. The objective of ETSAP is to assist decision-makers in the assessment of new energy technologies and policies in meeting the challenges of energy needs and economic development, environmental concerns and technology development.

ETSAP's strategy in achieving the objectives is twofold[4]. Through a common research programme, ETSAP established, maintains and enhances the flexibility of consistent multi-country energy/economy/environment analytical tools and capability (the MARKAL/TIMES family of models). ETSAP members also assist and support government officials and decision-makers by applying these tools for energy technology assessment and analyses of a wide range of energy and environment related policy issues.

In the period 2005-8 under Annex X "Global Energy Systems and Common Analyses"[5] the main objective was

(a) to carry out common global analysis

(b) to implement a global / national modelling framework

(c) to maintain and enhance the existing capabilities and tools

(d) to expand the framework for ETSAP expertise and tools.

As illustrated by this report, numerous activities have been undertaken aimed at achieving these objectives. This report presents the main advancements, applications, and accomplishments of collaborative, national and group activities of ETSAP in the period 2005-8, with special focus on energy models, scenario studies and policy evaluations.

1.2 Participation and Coordination to Other Bodies

The following contracting parties[6] (countries) have actively participated in Annex X: VITO and Uni-Leuven (Belgium), NRCan and GERAD (Canada), Risoe (Denmark), IPTS (DG RTD, Energy Office, European Commission), TEKES and VTT (Finland), Uni-Stuttgart IER (Germany), CRES (Greece), CNR/IMAA (Italy), JAERI (MEXT Japan), KEMCO (Korea), Uni-Chalmers (Sweden), PSI (Switzerland), BERR-AEAT (UK), BNL and EIA (US).

Towards the end of the Annex X IFE (Norway) and ECN (Netherlands) rejoined ETSAP and France joined for the first time. With the support of the IEA Networks of Expertise in Energy Technology (IEA/NEET) the Operating Agent of ETSAP has approached several other organizations in Austria, Brazil, China, India, Russia, South Africa, Spain, and Turkey. Some of them have also expressed keen interest in participating in ETSAP and have been invited to join by the Executive Committee.

ETSAP members work closely with users of its analytical tools[7]. Benefits are mutual. New model users learn to understand the capability of the model in addressing issues related to energy, the environment, innovative technologies and the economy. ETSAP experts learn from new model users wider energy and environmental issues that need to be addressed in a way that is tractable analytically. ETSAP members have been working with the following organizations over the past three years:

- the International Energy Agency (IEA), for its Energy Technology Perspective (ETP) project:
- the U.S. Energy Information Administration (EIA), for the development and use of the System for Analysis of Global Energy Markets (SAGE) and its publication "International Energy Outlook;"
- the European Commission, where several contracting parties participate to various research and policy studies, including CASCADE MINTS, NEEDS, RES2020, TOCSIN, REACCESS;
- The European Fusion Development Association (EFDA) and some EURATOM associates for the assessment of new power plant concepts;

[2] The full report is downloadable from www.etsap.org/official.asp.

[3] A short summary of ETSAP is presented in Appendix A.

[4] The Objectives and the full text of the ETSAP implementing agreement are reproduced in Appendix B; it is downloadable from www.etsap.org.

[5] The text of Annex X is reproduced in Appendix C.

[6] The full list of contracting parties and delegates to ETSAP is reported in Appendix D.1.

[7] The full list of licensed ETSAP tools users is reproduced in Appendix D.2.

- the Energy Research Institute of National Development and Reform Commission of China, the Tsinghua University and other Institutes for the development of China energy models with ETSAP tools;
- the Indian Institute of Management, Ahmedabad (Prof. Shukla) for the development of long-term Indian energy models with ETSAP tools;
- the Brazilian Ministry of Mines and Energy (MME), Centro de Pesquisas de Energia Elétrica (CEPEL), and Empresa de Pesquisa Energética (EPE) for evaluating the use of ETSAP tools and building a multi-region Brazilian model;
- the South African National Energy Research Institute (SANERI) and the University of Cape Town for analyses related to long term energy scenarios for Africa;
- user's groups in South East Asia (Indonesia, Malaysia, Philippines, Thailand and Vietnam), supported by the Australian Agency for International Development [AusAID], and in South East Europe (Albania, BIH, Bulgaria, Croatia, Kosovo, Macedonia, Montenegro, Romania and Serbia), supported by USAID, for multi-year capability building undertaking in energy modelling and policy assessment, and
- the International Energy Workshop (IEW), formerly linked to the Institute for Applied Systems Analysis (IIASA, Vienna) and now coordinated by Stanford University/Electric Power Research Institute (EPRI) and Resources For the Future (RFF).

The cooperation activities of ETSAP are financed by the contracting parties at a level of about two hundred thousand euros per annum. This has been used mainly to leverage from international and national research institutions and collaboration to reach the [much higher] funding level needed to carry out the activities illustrated in what follows.

1.3 Major achievements: Global Modelling Milestones using the ETSAP Tools

The full report illustrates fifty or more models, studies and analyses carried out with ETSAP tools. Among the many accomplishments achieved during Annex X two global model development undertakings stand out and deserve special accolades, as they have brought the state-of-the-art for comprehensive energy system analysis to new heights. These are the global applications associated with the publication of the IEA *Energy Technology Perspective* (ETP) in 2006/2008, and the assessment of possible routes to climate stabilization using ETSAP TIMES Integrated Assessment Model (TIAM). Each of these high-profile successes have established their relevance and are quickly becoming an integral part of international discussions on energy policy and pressing concerns arise from global Climate Change. An overview of each of these is provided here, and expanded upon in the body of the Report.

1.3.1 Energy Technology Perspectives 2008[8]

Secure, reliable and affordable energy resources are fundamental to economic stability and growth. The erosion of energy security, rising energy costs, the threat of disruptive climate change and the growing energy needs of the developing world - all pose major challenges to energy decision makers. What visions of the future that could address these issues are technically feasible and available? Where do we need to focus? And who needs to act and when?

The IEA publication *Energy Technology Perspectives (ETP) 2008* (launched June 6, 2008) tackles these challenges and questions. Innovation in energy technologies and a better use of existing technologies will be fundamental to achieving important policy goals. The book provides an analysis of the status and future prospects of key energy technologies, and shows how they can contribute to a more sustainable, secure and least-cost energy system. It outlines the barriers to the implementation of change and the measures that would be needed to overcome these barriers. It explores how technology can change our energy future.

New Energy Technology Perspectives Insights

The *Energy Technology Perspectives 2008* study builds on the *ETP2006* and on the *World Energy Outlook 2007* and expands the analysis considerably. For the first time the IEA has published scenarios that aim for a halving of energy related CO_2 emissions by 2050.

The goal of the analysis is to provide a technology perspective on the feasibility and costs of deep emission reductions; the book includes various scenarios, amongst them an extremely ambitious one, showing how CO_2 emissions could be reduced to 50% below current levels by 2050. The analysis does not deal with the political feasibility of such targets. However, the results make clear that all countries need to act in the next few years if the goal of halving emissions is to remain affordable. In fact the analysis suggests that such action could also greatly enhance the supply security.

This is the first time that supply and demand side financing needs for technology deployment and commercial investments are elaborated in detail. This study contains roadmaps for all technologies that play a key role in the

[8] Paper prepared for the International Energy Workshop, Paris, 30 June-2 July; corresponding author: dolf.gielen@iea.org.

emissions halving scenario. Also energy related methane emissions and their reduction are discussed. The data for key technology areas have been updated, and the scope of the technology discussion has been broadened.

The Baseline energy demand and emission projections has been revised upward, compared to *ETP2006*. The average growth rate is 3.3% per year.[9] From 2005 to 2050, GDP quadruples from around USD 50 trillion per year to around USD 200 trillion per year. This growth is essential to lifting millions in developing countries out of poverty, and the same economic growth rate has been applied in all scenarios.

The book contains three major sections:

Part I: *Technology and the Global Energy Economy to 2050*
This section presents a set of scenarios to 2050. These scenarios analyse the role energy technologies and best practices aimed at reducing energy demand and emissions and diversifying energy sources can play. While the Baseline scenario is descriptive (policies in place to date, consistent with the IEA *World Energy Outlook* 2007 Reference Scenario), the ACT and BLUE scenarios assume new, ambitious policy targets (emission stabilization and halving, respectively).

To meet the most ambitious IPCC scenario aimed at keeping global average temperature increase below 2.4°C, global CO_2 emissions would need to be halved by 2050 compared to their current levels. G8 leaders at the Heiligendamm summit in 2007 agreed to seriously consider a 50% reduction target. The ETP BLUE scenarios explore this target and its energy technology consequences. The goal is challenging, requiring dramatic changes in the way we produce and use energy, with action required globally in the next few years. Oil demand in the BLUE scenarios is below today's level. This is the first time that the IEA releases energy scenarios where oil demand declines.

Part II: *The Transition from the Present to 2050*
These chapters examine strategies that use energy technologies to help the world move towards a more sustainable energy future and offers technology roadmaps that can achieve this objective. This section also explores the roles of RD&D (research, development and demonstration), deployment and investment (the three steps in the technology lifecycle) in supporting policy outcomes.

Part III: *Energy Technology: Status and Outlook*
The final section provides a detailed review of the status and prospects of key energy technologies in power and heat generation, road transport, industry, and buildings. It highlights the potential of technologies in these sectors and their costs, and discusses the barriers that each technology must overcome before its full potential can be harvested.

A 15-region MARKAL model of the world energy supply and demand is the analytical backbone. For the ETP2008, this has been complemented with spreadsheet models for the three end-use sectors: transportation, industry and buildings. These end-use sector models are detailed at the level of G8+5 countries and world regions.

The BLUE Scenarios and the Role of Energy Technologies

The ACT and BLUE scenarios represent sets of optimal pathways to reduce energy-related greenhouse gas emissions, to the scenario goal, while at the same time, also enhancing the security of supply. The demand for energy services is the same in all scenarios – that is to say, no change in lifestyles is assumed - but the technology mix is radically different.

The family of ACT scenarios describe least-cost pathways to return energy CO_2 emissions back to 2005 levels by 2050. There are five ACT scenarios. In addition to the ACT MAP scenario, there are variants with different assumptions for key technology options for power supply (nuclear, CO_2 capture and storage, renewables) and end-use efficiency. The ACT Map scenario is the central variant with relatively optimistic assumptions for all technologies.

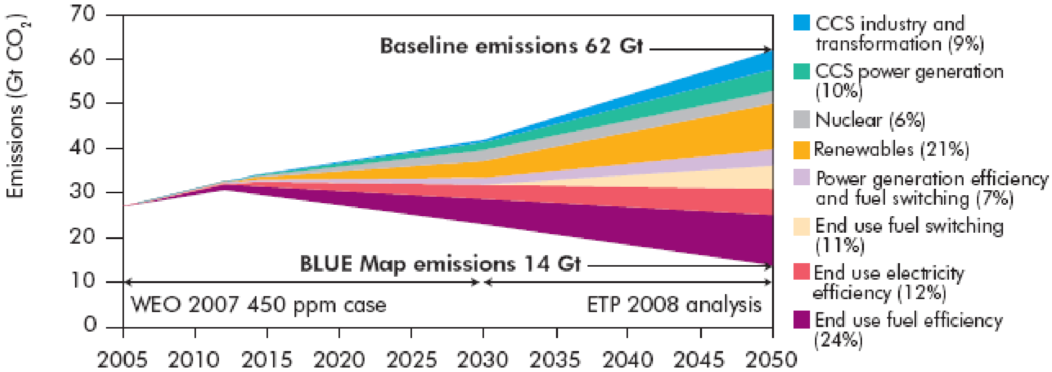
The BLUE scenarios describe least-cost pathways to reach a 50% reduction of CO_2 emissions by 2050 compared to the level of 2005. For the power sector the same five areas of uncertainty as for ACT have been covered through the same five sets of assumptions, but it also contains four sets of assumptions for the transport sector. This gives a total of twenty BLUE scenario variants. The BLUE Map scenario is the central variant.

The study concludes that end-use efficiency and a virtually CO_2-free power sector can yield emissions stabilisation in 2050 at today's level (the accelerated technology scenario ACT). However, halving emissions would also require significant fuel switching, CO_2 capture and storage in end-use sectors and steps to ensure that rapidly growing emissions from transport are not just slowed, but reduced. The BLUE scenarios are therefore more challenging, require earlier and stronger action, and they will be much more costly.

The scenarios require a broad portfolio of technologies to be used. End-use efficiency accounts for 36% of all savings in the BLUE Map scenario, renewables for 21%, and CO_2 capture and storage 19%. The remaining 24% is accounted for by nuclear, fossil fuel switching and efficiency in power generation (Figure 1-1).

[9] Purchasing Power Parity based

Figure 1-1: Contribution of emissions reductions options in the BLUE Map Scenario of ETP 2008, between 2005 and 2050



The average annual investments between 2010 and 2050 needed to achieve a virtual decarbonisation of the power sector, include, among others: 55 fossil-fuelled power plants with CCS, 32 nuclear plants, 17 750 large wind turbines, and 215 million square metres of solar panels (Figure 1-2). Although such rates of new technology adoption may seem daunting the historical rate of nuclear addition and that of current onshore wind additions suggest that they are achievable. Investments in CO_2-free power generation need to increase six- to sevenfold, from around 50 GW per year today to 330 GW per year in the period 2035-2050.

The BLUE scenario also requires widespread adoption of very energy-efficient buildings, with near zero emissions; and, on one set of assumptions, deployment of nearly a billion electric or hydrogen fuel cell vehicles. Sales of conventional vehicles with internal combustion engines would be all but phased out in 2050.

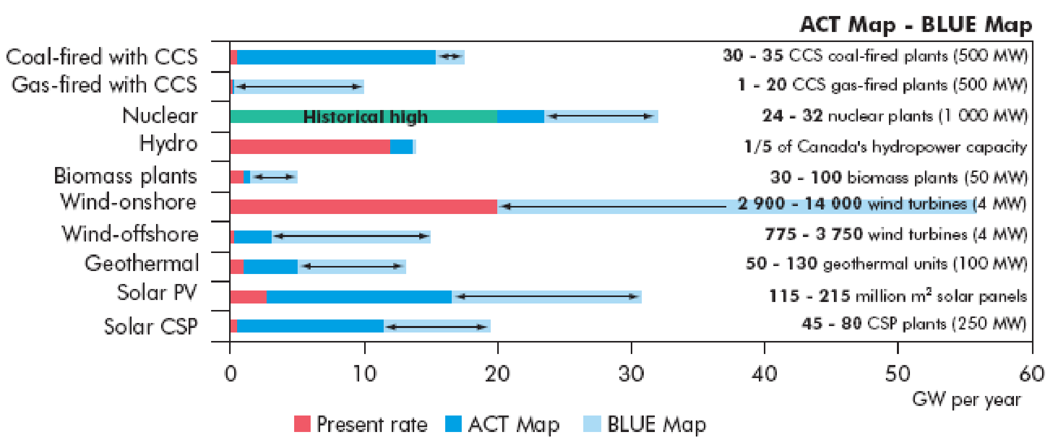
Compared to previous IEA scenarios, the outlook is considerably more optimistic for renewables and for nuclear energy. The electricity mix in BLUE Map consists of nearly half renewables, a quarter nuclear and a quarter fossil fuels with CO_2 capture and storage. In the scenario which halves CO_2 emissions, renewables account for up to 46% of total power generation. Hydro, wind and solar each provide around 5000 TWh in 2050.

In the transport sector, plug-in hybrid electric vehicles and battery electric vehicles have emerged as a promising strategy and are now a key part of some of the more ambitious scenarios.

While energy efficient equipment is available today, more ambitious standards and regulations are needed to ensure its rapid uptake. Significant cost reductions will also be needed in some cases in order to lower the cost of abatement in difficult market segments. The average energy efficiency in 2050 needs to be twice the level of today, a significant acceleration compared to the developments in the last 25 years.

The Baseline scenario would require a massive expansion of fossil fuel production, to an extent that calls into question supply availability. For example oil production would have to rise from today's level or around 85 million barrel per day to around 135 million barrels a day in 2050. Even if such an expansion was feasible, it would require a massive production of oil from unconventional resources.

Figure 1-2: Annual investment in the electricity sector in the ACT Map and Blue Map scenarios, 2010-2050



In contrast, oil demand in BLUE Map in 2050 is 27% below the level of 2005. Such a development would certainly ease the supply challenge. However even this level of production will require massive investments in new supply in the coming years and decades as oil fields are depleted. Total fossil fuel demand in the extreme BLUE Map scenario in 2050 is still at the same level as today. So in any case fossil fuels will continue to be a key pillar of our energy supply in the coming decades.

To meet the BLUE scenarios, we need to urgently develop and implement new far-reaching policies to a degree unknown in the energy sector and to substantially decarbonise power generation. A significant discrepancy exists between current trends and the BLUE scenario targets. We will need to launch in the coming decade a global revolution in the way we produce and use energy, with a dramatic shift in government policies and unprecedented co-operation amongst all major economies.

The Financing Needs

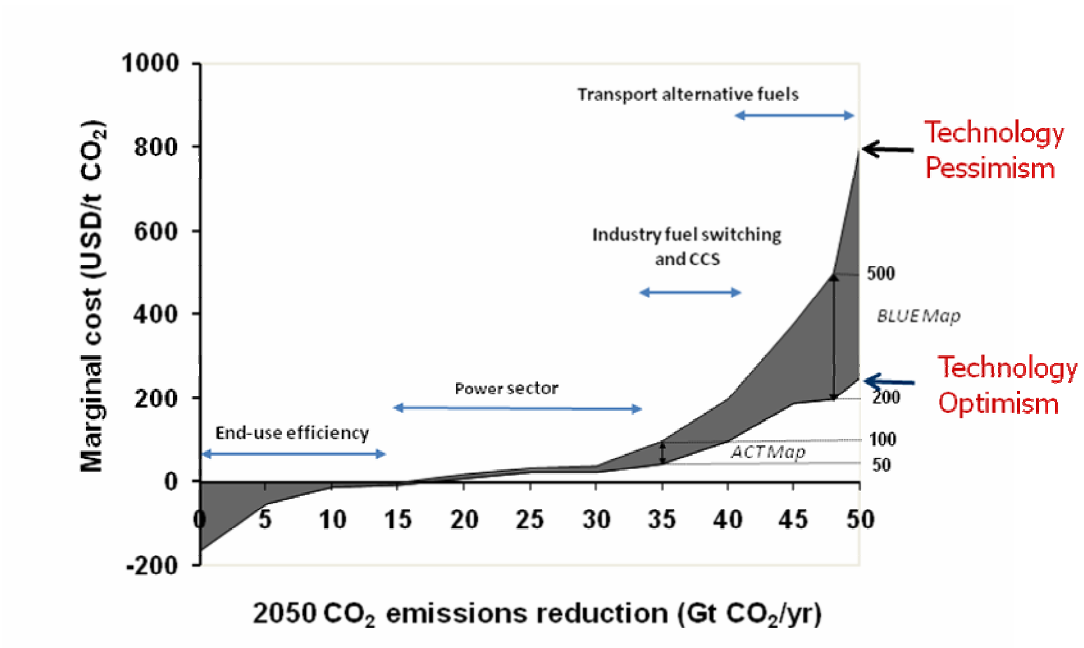
The marginal cost and financing required to achieve these scenarios represent an important outcome of the study. The ACT Map scenario requires options with a marginal cost up to USD 50/t CO_2. This figure is double that reported in ETP2006. There are a number of reasons: higher economic growth projections, rising materials and engineering costs, new technology insights and the declining value of the United States dollar (all costs have been evaluated in US dollars).

The BLUE Map scenario requires options with a marginal cost up to USD 200/t CO_2.[10] These marginal cost estimates are based on reasonably optimistic assumptions about significant technology cost reductions. Assuming less optimistic cost reductions, notably in the transport sector, would result in the marginal cost for BLUE rising to up to USD 500/t CO_2. A key insight is that the cost uncertainty increases for more ambitious targets, as technologies are needed that are not yet mature and whose future cost are therefore highly uncertain. The average emissions reduction costs in BLUE Map are about a fifth of the marginal cost, and range from USD 38/t CO_2 to USD 117/t CO_2.

The options can be grouped into distinct categories, indicated in Figure 1-3. This suggests that a generic pricing approach may not be the best way to achieve substantial emissions reductions.

Increased energy technology R&D will be essential. Current technology RD&D investments by IEA governments amount to around USD 10 billion per year, and industry spends around USD 40 billion per year.[11] Efficiency, re-allocation and increased spending can all help to achieve the rate of RD&D change that is needed. Consequently, the actual level of additional funding that is needed is unclear. Literature suggests a range of USD 10 to 100 billion a year. Given the current total level of spending the higher end of this range seems more likely.

Figure 1-3: Marginal abatement cost curve, 2050



[10] USD 200/t CO_2 translates into additional cost of USD 80/bbl of oil.

[11] This is a preliminary estimate. The share of energy spending in total private sector RD&D needs to be analysed in greater detail.

Apart from RD&D, significant deployment investments are needed in order to achieve the necessary learning effects that reduce the cost of achieving the ACT and BLUE scenarios. Total learning investments – on top of Baseline investments – amount to USD 1.75 trillion between 2010 and 2030, and USD 5.25 trillion between 2030 and 2050 in the BLUE scenario.

The total investment needs in ACT Map for the period 2010-2050 are USD 17 trillion higher than in Baseline, and this rises to USD 45 trillion in BLUE Map. These are the optimistic cost estimates with substantial technology learning and least-cost investments. Investment needs would be higher in the event of less technology learning progress. The investment figures include the investment to achieve massive gains in end-use efficiency, which in turn reduce investment needs in power generation and fuel processing. Clearly the activation of this efficiency potential through standards and regulation will be an important challenge.

The pattern that emerges is one where additional investments amount to USD 100-200 billion per year in the coming years; this needs to increase to USD 1-2 trillion by 2030 and USD 2-5 trillion per year in 2050. The range reflects the uncertainty of future technology cost. Although these figures seem large, they should not be viewed in isolation. The additional investments represent a huge sum, but to put it into perspective 2 trillion equals 1% of world GDP in 2050.

The additional investment needs are balanced by lower fossil fuel expenses (an undiscounted amount of USD 51 trillion, if valued at market prices). The net outcome depends on the discount rate for future fuel savings and the value used for fuel prices (market prices or production cost). However, in the BLUE Map scenario the additional investment needs exceed fuel savings by USD 0.8 trillion (assuming 3% discount rate and market fuel prices).

An important issue is the uneven distribution of burden across countries. Energy exporting countries would face a GDP reduction of 10%, while major developing countries such as China and India would face a reduction of around 5%. The cost would be relatively modest for OECD countries (OECD, 2008). Therefore burden sharing across regions and sectors will be an important theme in the negotiations about a post-Kyoto framework.

The technology mix is another key outcome of the study. The rate of change that is needed is unprecedented. The analogy is not that we need an Apollo project or other grand undertaking, but more like we need an energy technology revolution. While the necessary technologies are ready or being tested on a pilot scale, their mass application is in many areas still far away, while for many, costs must also come down. The rate of technological change in many areas is in the order of decades. Important issues are the rapid build-up of mass production capacity required, as well as the barrier to rapid change that the life-span of existing capital stock, planning procedures and public acceptance represent.

An important insight is that the future energy system will be determined by decisions taken in the next few coming years and that not acting now with policies to achieve the ambitious long–term goal implied by the BLUE scenario will impose higher costs in the future. Clear long-term targets are needed to convince decision makers in industry to make the capital investments needed to dramatically change our energy system. Technology learning investments are needed to achieve the necessary cost reductions for more sustainable technologies. Energy RD&D levels must be raised and restructured in order to accelerate the development of new energy technologies with superior characteristics.

Next Steps

The report contains roadmaps for 17 groups of technologies that cover over four fifths of the total emissions reduction (Table 1-1). These roadmaps describe the role of technologies in the ACT Map and BLUE Map scenarios, and give RD&D and implementation targets and policy needs for the period between now and 2050 that must be met in order to be consistent with the desired 2050 outcome – so-called transition paths. These roadmaps need further development in the coming months and years, and building an international implementation framework supported by the public and private sector will be essential. Closer international cooperation will be needed. Indicators must be elaborated and used to track progress on the roadmaps. These roadmaps should not be straightjackets but signposts that guide the developments and accelerate the change towards a more sustainable energy future. The IEA and its Implementing Agreements are ready to support the major economies in the roadmap progress.

Table 1-1: ETP Roadmaps

Supply Side	Demand Side
• CCS fossil-fuel power generation	• Energy efficiency in buildings and appliances
• Nuclear power plants	• Heat pumps
• Onshore and offshore wind	• Solar space and water heating
• Biomass IGCC & co-combustion	• Energy efficiency in transport
• Photovoltaic systems	• Electric and plug-in vehicles
• Concentrating solar power	• H_2 fuel cell vehicles
• Coal: integrated-gasification combined cycle	• CCS industry, H_2 and fuel transformation
• Coal: ultra-supercritical	• Industrial motor systems
• 2^{nd} generation biofuels	

1.3.2 The ETSAP TIMES Integrated Assessment Model (TIAM)

The ETSAP-TIAM[12] (TIMES Integrated Assessment Model) is a detailed, technology-rich global TIMES model. It is the synthesis of the experience and technical excellence embodied in ETSAP and its tools. The results of ETSAP-TIAM studies have wide diffusion among the groups that assess climate mitigation policies through EMF and IPCC, and said team has been invited to continue to contribute in both prestigious undertakings. Here an analysis examining *Hedging Strategies for Climate Stabilization* [13] is presented to illustrate the application of the model, while in Section 2 of the main report an overview of the ETSAP-TIAM model structure and features is given along with addition application examples.

Introduction

The Energy Modeling Forum (EMF) is a long standing international forum based at Stanford University, which brings together the leading global energy modellers to look at the pressing energy and environmental issues. Over the last three decades, EMF has defined and organized 23 work programs, each on a specific theme. The current pertinent exercise, EMF-22, is about long term climate stabilization and policies to achieve such. It has four Work Groups, each tackling one aspect of the central theme:

- WG1: Hedging Strategies for long term climate stabilization;
- WG2: Transition Policies in the context of Climate Stabilization;
- WG3: Black Carbon / Organic Carbon, and their effect on radiative forcing, and
- WG4: Land-use changes and their effect on emissions.

ETSAP participated in WG1 from 2004 to 2006 (with additional tail activities in 2007) and is participating in WG2 since 2006 (but delays occurred within WG2; which could prolong it till 2009).

Base assumptions

The following main guiding assumptions – an alternate experiment assumes a more gradual resolution of uncertainty, but was not being treated with TIAM – were defined by WG1, to be followed by all modellers in that WG are stated here.

- Horizon length left to the choice of each *modelling* team, but recommended to be as long as possible. For TIAM: horizon extends to 2100.
- GDP growth reference scenario is chosen by each modelling team. For TIAM, we chose a reference GDP scenario close to the B2 storyline proposed by the Intergovernmental Panel on Climate Change (IPCC), i.e. moderate economic growth of GDP, and world population almost stagnating after 2050. The base case GHG emission trajectory as well as the atmospheric GHG concentration reached in 2090 are fairly close to the B2 Emission Scenario of the IPCC-SRES. CO2 remains the most important GHG (around 79%), followed by CH4 (around 19%) and N2O (less than 2%).
- Economic development (represented by GDP growth rate) is assumed known until 2040 and uncertain after 2040, with two equally probable values, namely: i) GDP = 2/3 * GDP_{ref} with probability 0.5, and ii) GDP = 4/3 * GDP_{ref} with probability 0.5. In 2040, GDP rate is revealed for all years of the horizon
- Uncertainty of the Climate Sensitivity parameter (Cs) is assumed. The Climate Sensitivity (**Cs**) can have values 1.5 ºC, 3 ºC, 5 ºC, 8 ºC with probabilities 0.25, 0.45, 0.15 and 0.15 respectively. Uncertainty prevails until 2040, and is fully resolved in 2040.
- Stabilization of global temperature to 2^{o}C or 3^{o}C

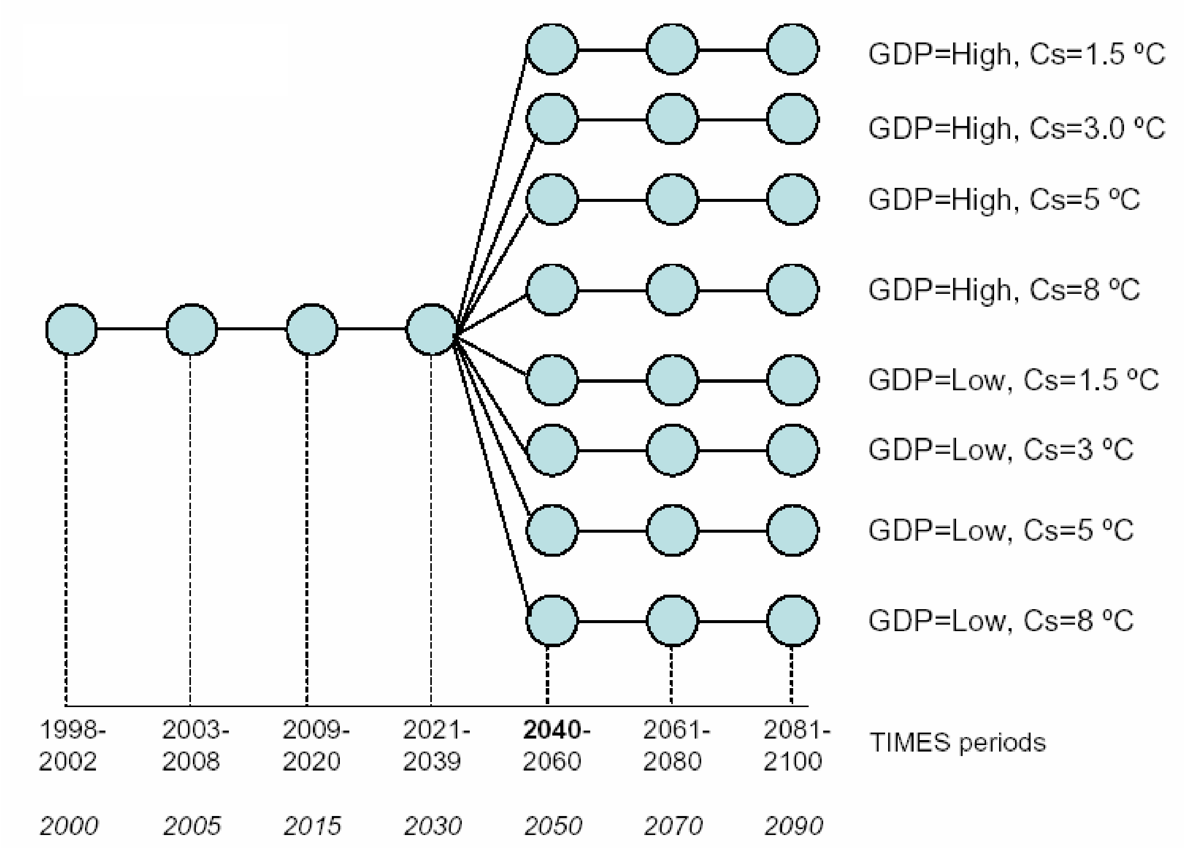
The above scenario was implemented in TIAM via Stochastic Programming in extensive form[14]. For a given temperature target, the uncertain parameters are (as illustrated by the event tree of Figure 1-4): i) the climate sensitivity Cs (four possible values), and ii) the vector of energy service demands resulting from the future economic growth (two possible values), with the uncertainties resolved in 2040.

[12] Contact: maryse.labriet@ciemat.es.

[13] In Summer 2004, ETSAP mandated Richard Loulou (KANLO) and his team (Amit Kanudia, Maryse Labriet) to participate in the Energy Modeling Forum (EMF-22) on behalf of ETSAP, and to use ETSAP's TIAM (TIMES Integrated Assessment Model) to provide inputs into the EMF-22 process. Contact: maryse.labriet@ciemat.es.

[14] This feature was developed by Richard Loulou, Antti Lehtilä and Amit Kanudia in view of the application to EMF-22, and was especially adapted and coded by Antti Lehtilä (VTT, Finland). In particular, the TIMES code was modified to allow Cs and several other parameters to be uncertain (for details, refer to the documentation of the Stochastic feature on ETSAP web site).

Figure 1-4: Event Tree Implemented in ETSAP-TIAM for EMF-22.



Main findings: impact of the uncertainties and expected value of perfect information

After conducting stochastic optimizations with the 8 States of the World (SOW), it was observed that the impact of economic uncertainty on the hedging strategy before 2040 was negligible. In other words, the hedging decisions taken before 2040 are quite insensitive to the values of economic demands (and therefore the emission levels) after 2040 (there is no anticipation effect).

On the contrary, the impact of climate uncertainty is huge. As shown in Figure 1-5, if the climate sensitivity happens to be 1.5 ºC achieving stabilization at 2.5-2.7 ºC temperature targets is not demanding; the contrary is true if the climate sensitivity is as high as 8 ºC.

Figure 1-5: Global Emissions for a Hedging Strategy

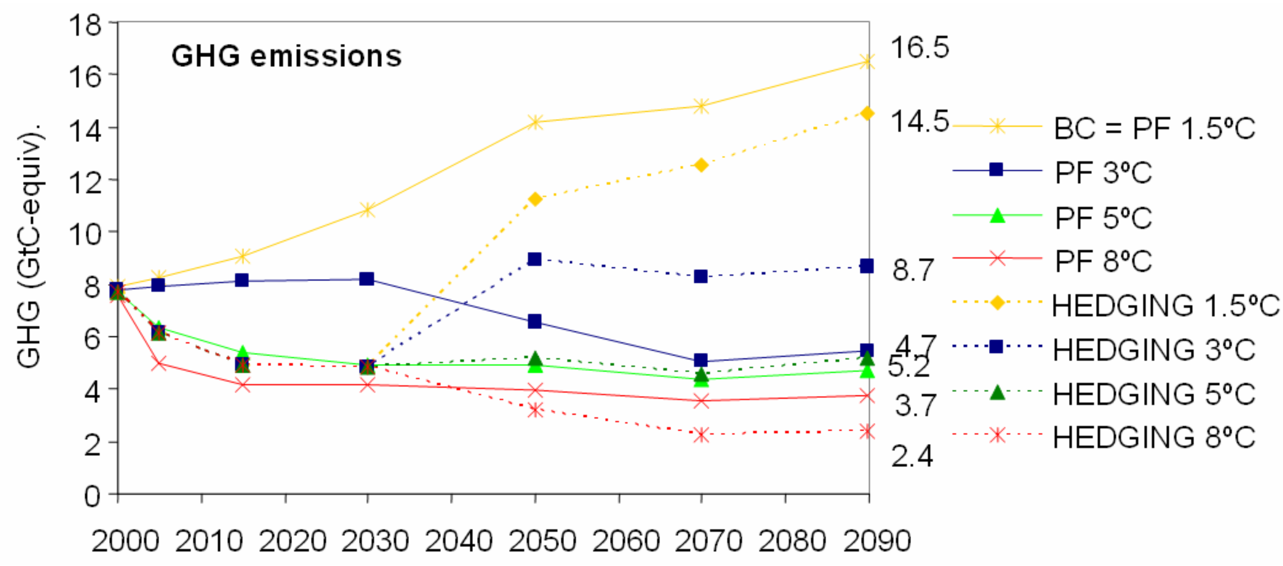


Table 1-2: Loss of Surplus and Expected Value of Perfect Information

Strategy	Loss of Surplus ($NPV_{5\%}$ in B$)	Probability	Expected Loss (NPV in B$ and annuity in B$/year)	EVPI (NPV in B$ and annuity in B$/year)
Base	**0**	**1**	**-**	**-**
PF Cs=1.5°C	0	0.25	-	-
PF Cs=3°C	43	0.45	-	-
PF Cs=5°C	580	0.15	-	-
PF Cs=8°C	3353	0.15	-	-
Total PF			***610 (31)***	**-**
Hedging	**820**		**820 (41)**	**210 (11)**

The overall net present value (NPV) of the surplus attached to a climate strategy represents a compact measure of the social welfare associated with that strategy. Table 1-2 shows the expected loss of total surplus of the hedging strategy and of the perfect forecast strategy, relative to that of Base taken as reference. The loss of surplus when following Hedging is 35% higher than the expected loss for the perfect information strategy. This difference represents the expected value of perfect information (210 B$ in NPV).

Main findings: implications of six alternative stabilization targets

As shown in Table 1-3, six long range temperature change targets were attempted, ranging from 2.1 to 3.3 °C. Targets 2.1°C and 2.3°C are very expensive to attain, and target 3.3°C is quite easy to attain.

Amongst the most noticeable results of the hedging strategies, the model reveals that the smallest achievable temperature increase is close to 1.9ºC, albeit at a very large cost, by a combination of energy switching, capture and storage of CO2, CO2 sequestration by forests and non-CO2 emission reduction options. This means that more severe temperature targets would require additional GHG abatement potential that is currently not yet seen as realistic. Moreover, the impact of uncertainty of the climate sensitivity parameter Cs is major, requiring the implementation of early actions (before 2040) in order to reach the temperature target. Therefore a "wait and see" approach is not recommended.

Robust abatement options include: substitution of coal power plants by hydroelectricity, sequestration by forests, CH4 and N2O reduction. Nuclear power plants, electricity production with CCS, and end-use fuel substitution do not belong to early actions. Among them, several options appear also to be super-hedging actions i.e. they penetrate more in the hedging strategy than in any of the perfect forecast strategies (e.g. hydroelectricity, CH4 reduction), proving that stochastic analysis of future climate strategies might give insights that are beyond any combination of the deterministic strategies. In contrast, the uncertainty of the GDP growth rates has very little impact on pre-2040 decisions. This insensitivity is a pleasant surprise, as it shows that a hedging strategy for only one random parameter (Cs) is also a quasi-optimal strategy when the two types of uncertainty are present.

As for sector emissions in the base case, the electricity and transportation sectors are the highest GHG contributors in 2000 (more than 40% of total GHGs), and the electricity and industry sectors become the highest contributors at the end of the horizon (more than 48% of total GHG). The situation is radically different under the 2.5ºC temperature constraint, where both the electricity and industry sectors are able to reduce to almost zero (less than 3% of total GHG) their emissions in the most stringent branch, mainly thanks to CCS in the electricity sector, and switching to electricity in the industrial sector. In this most stringent branch, transport and agriculture are the highest remaining GHG contributors (30% and 41% of total GHG)[15].

Table 1-3: Net Present Value of total cost for six alternative stabilization targets (hedging)

T_{2090}	T_{max} (long term)	Cost ($G\$_{2000}$)	Annuity ($G\$_{2000}$)
1.4 °C		*Infeasible*	
1.5 °C	2.1 °C	12253	617
1.6 °C	2.3 °C	4398	221
1.8 °C	2.7 °C	820	41
2.0 °C	3.3 °C	121	6
2.3 °C	**4.6 °C**	**Base Case**	

[15] No such drastic decrease of CH4 emissions is possible because some non-energy agriculture-related sources have no abatement options in the model.

Conclusion: the advantage of hedging strategies

Target 2.7°C was investigated in more detail. In addition to the hedging strategy, we also computed four (deterministic) perfect forecast strategies (noted PF), each assuming that the value of Cs is known as early as the first period. The theoretical interpretation of the four PF strategies is that of an optimal strategy if one assumes that the uncertainty is resolved at the beginning of the horizon.

The NPV of overall expected cost is equal to 820 G$ (to be precise, the cost is to be understood as loss of total surplus). Main hedging actions before 2040 are:

- replacement of coal power plants by wind, hydro, and gas plants;
- biological CO_2 sequestration by forestry measures;
- many targeted CH4 and N2O abatement actions;
- slightly more nuclear power plants, and
- note that CCS actions and hydrogen are ***not*** part of the hedging strategy prior to 2040.

The comparison of hedging with perfect forecast strategies shows that a deterministic strategy with Cs=5ºC is closest to the hedging strategy. However, the two differ in several key aspects, and this confirms the relevance of using stochastic programming in order to analyze preferred climate policies in an uncertain world where the correct climate response is known only far into the future. In particular, the perfect forecast strategy provides a poor approximation of the optimal electricity production mix, of the price of carbon, and of the penetration of several sequestration options.

This exercise has shown that hedging is a useful concept when facing climate uncertainty, and Stochastic programming a powerful way to compute hedging strategies. The alternative approach of using alternate scenarios is not an effective way to resolve the dilemma facing policy makers when confronted to an uncertain.

1.4 Snapshot of ETSAP Participant Activities

The various ETSAP Partners have been involved in numerous model development, outreach and application undertakings. A snapshot of these is provided in Table 1-4, and, elaborated upon in the full report.

Table 1-4: Overview of Annex X Activities and Accomplishment

Conducted by	Title/Group	Key Activities/Findings
International Applications Using Global Models		
IEA Energy Technology Perspectives	Publication of ETP 2006: Scenarios and Strategies to 2050 - The Outlook to 2050 and the Role of Energy Technology	"Secure, reliable and affordable energy supplies are fundamental to economic stability and development. The threat of disruptive climate change, the erosion of energy security and the growing energy needs of the developing world all pose major challenges for energy decision makers. They can only be met through innovation, the adoption of new cost-effective technologies, and a better use of existing energy-efficient technologies. Energy Technology Perspectives presents the status and prospects for key energy technologies and assesses their potential to make a difference by 2050. It also outlines the barriers to implementing these technologies and the measures that can overcome such barriers."
	Publication of ETP 2008: Scenarios and Strategies to 2050 - Scenarios and the Role of Energy Technologies	"The IEA analysis demonstrates that a more sustainable energy future is within our reach, and that technology is the key. Increased energy efficiency, CO2 capture and storage, renewables, and nuclear power will all be important." End-use efficiency and a virtually CO_2-free power sector power sector can hold 2050 emissions at today's levels; the marginal cost of abatement varies widely for different assumptions for technology advancement. Roadmaps are provided for 17 groups of technologies that cover four fifths of total emissions reductions.
	ETP2006 Target Analysis - Prospects for CO_2 Capture and Storage (CCS)	CCS has the potential to reduce emissions between 5.5 and 19.2Gt in 2050. With an emission penalty of 50 USD/t, without CCS emissions would be higher by 25%.
	ETP2006 Target Analysis - Prospects for Hydrogen and Fuel Cells	With aggressive policy actions and favourable technology developments, 30% of global vehicles could be powered by hydrogen fuel cells by 2050 – about 700 million vehicles – displacing 15 million barrels/day of oil [13%] of global oil demand.
	ETP2006 Target Analysis - Industrial Energy Use	In a business-as-usual scenario, industrial CO_2 emissions would almost double by 2050. Emissions could be stabilized by policies that promote the rapid adoption of existing and new technologies.
ETSAP	Hedging Strategies for Climate Stabilization with ETSAP-TIAM	Six long range temperature change targets from 2.1 to 3.3 ^{o}C were analyzed [Reference increase 4.6 ^{o}C; smallest achievable increase 1.9 ^{o}C at very high cost.] Targets 2.1 and 2.3 ^{o}C are difficult and very expensive to attain, while 3.3 ^{o}C is quite easy.
	Technological Mitigation Under Capital Rationing: The Role of Nuclear Energy in Long-Term Climate Scenarios	Analysis of future investments in electricity producing technologies in large developing countries such as China and India under various conditions of capital rationing and carbon pricing.
	Studies with the Global MARKAL Models of the Paul Scherrer Institute	Effects of different levels of subsidies for renewable energy and implications of a "nuclear breakthrough" in combination with carbon taxes.

Conducted by	Title/Group	Key Activities/Findings
USDOE/Energy Information Administration	System for the Analysis of Global Energy markets (SAGE)	Integrating framework supporting the production of EIA's comprehensive *International Energy Outlook 2007*.
European Union	The Global TIMES Model of the European Fusion Development Agreement	Assessment of market potential for fusion to 2100.
Finnish Ministry of Environment/ VTT Energy Systems	Global Energy and Emissions Scenarios for Effective Climate Change Mitigation	Evaluation of achievement of the EU 2 ^{o}C stabilization target; the highest marginal costs occur around 2090, when the global price of emission permits reaches 150 Euros/t CO_2 equivalent.
UK-Japan Low Carbon Society Project	A Global Perspective to Achieve a Low Carbon Society	Without any reduction obligation, global CO_2 emissions in the base scenario more than double from 2000 to 2050 driven by economic growth in developing countries. Recommendations are provided to reverse this path,
Regional Applications		
European Union	The New Energy Externalities Development for Sustainability (EC-NEEDS) Project	Evaluation of the full costs and benefits of energy policies and of future energy systems for the "enlarged EU" (EU27 plus Iceland, Norway, and Switzerland) and for individual countries within this group. Follow-on EC funded projects will build on NEEDS.
	Studies with the EU30 TIMES-Electricity and Gas supply model	The role of combined heat and power and district heat in Europe, and the role of technology progress on investment decisions in the European electricity market.
	Europe - South East Asian Energy System Modelling and Policy Analysis (ESMOPO) Project	Possible future energy solutions for Vietnam, Indonesia, and the Philippines, with focus on renewable and advanced fossil power generation.
	Technology-Oriented Cooperation and Strategies in India and China (EC-TOCSIN) Project	30 month program initiated in 2007 to improve the depiction of India and China energy systems, and regions in global models. Results limited so far.
AusAID-EPSAP	The Energy Policy and Systems Analysis Project	A variety of policy studies of the region and individual countries indicates that LNG will play a major role in the region's future, renewables will likely require subsidy, and that there are clear benefits to regional [as opposed to national] strategies.
US Agency for International Development (USAID)	South East Europe Regional Energy Demand Planning (SEE-REDP): Future Energy Scenarios in Southeast Europe and the Potential for Energy Efficiency	Major capacity building undertaking involving 8 SEE countries. Established national models and examined increased investments in more efficient end-use technologies, highlighting that these costs are more than offset by significant reductions in fuel expenditures and modest reductions in the level of new investment in the power sector.

Conducted by	Title/Group	Key Activities/Findings
ETSAP Partner Country Studies		
Belgium	Analysis of Post Kyoto Mitigation Options with MARKAL-TIMES	Definition of the carbon reduction level for Belgium that is realistically achievable and under what conditions. A two-fold decrease seems achievable with a marginal cost not exceeding two-three hundred euros per ton CO2 if: the electricity generation sector compensates a slight reduction of nuclear with wind farms and biomass power plants; the transport sector halves its emission by increasing the use of biofuels, hybrid and CNG vehicles; civil sectors can reach a three-fold reduction; and the industrial sector halves its emissions by substituting electricity for other fuels, mainly natural gas.
Finland	The Impact of the Emissions Trading on Energy Sector and Steel Industry	Examination of how the emissions trading system affects the Finnish energy and steel sector companies and their competitiveness, when production volumes and the use of energy are increased in the open markets.
France	MARKAL/TIMES CO2 Emission Reduction Scenarios	Analysis to date indicates that it is possible to achieve very stringent CO_2 reductions, although at significant cost in the more extreme cases.
Germany	Investments in the German Electricity Generation Sector: Technology Perspectives and Climate Protection	Scenario analyses have shown that the significant CO_2-emission reductions can be reached without taking a strong burden on the energy system. First it has to be made sure, that the political framework for the deployment of clean coal technologies with carbon capture and storage for electricity generation will be developed. Second it has been shown, that especially nuclear-based electricity generation can contribute to the emission reduction targets at low costs.
Italy	The MARKAL-MACRO-Italy model for evaluating national energy environment policies	Identification of the potential contribution of different technological options to reach the EU 20-20-20 targets and impact for Italy of different implementation measures.
	The Italian Electricity Sector: A Regional and Multi-Grid TIMES Model	A very detailed: 5 sectors, 32 energy services and 150 end-use technologies in the demand side and about 450 power plant units in the supply side; 20 Regions, 5 electricity commodities spread over 4 types of grid for transport, transformation and distribution is modelled. Inter-regional exchange technologies are described with costs, installed capacity and efficiency of transportation. The paper presents a selection of results concerning scenarios with different role of electricity import, renewable sources, emission permit developments and “end-uses technologies.”
The Netherlands	The ECN MARKAL-Europe Model - Planning for a Domestic Electricity Sector with CO2 Capture and Storage	Emission reduction: If hydrogen is introduced into the energy system, the costs to reduce one unit of CO2 decreases by 4% in 2030 and 15% in 2050, implying that hydrogen is a cost-effective reduction option given the input assumptions. How a trajectory towards an electricity sector with CO2capture and storage (CCS) can be achieved.
Norway	Reducing Domestic Greenhouse Gas Emissions By 75 % by 2050	Institute for Energy Technology (IFE) has been involved in the work of the Norwegian Commission on Low Emissions to carry out technological assessments and to use the Norwegian MARKAL model to study alternative options to reduce greenhouse gas emission. In total, IFE has described measures, which can give more than a 75 percent reduction in Norwegian emissions by 2050.
Sweden	Recent MARKAL-TIMES Modelling and Analysis Activities at Chalmers University of Technology	At Chalmers University of Technology MARKAL/TIMES have been involved in a study on CO2 reduction in Sweden comparing cost-efficiency in the stationary energy and transport sectors using the MARKAL_Nordic model, a regional modelling analysis of biomass use under different energy policies with particular focus on biomass gasification, the Europe - South East Asian Energy System Modelling and Policy Analysis Project (ESMOPO), and the development of the TIMES Sweden and Norway models.
Switzerland	The Vision of a 2000-Watt Society	Partial but significant success in meeting the vision of 2000-Watts is obtained. The results suggest that the 2000-Watt society should be seen as a long-term goal.

Conducted by	Title/Group	Key Activities/Findings
United Kingdom	MARKAL- Macro Analysis of Long Run Costs of Mitigation Targets in the UK	Marginal abatement costs increase significantly as emission reduction targets are increased. For a 60% reduction, costs were approximately £65/tCO_2 (£240/tC). These increase to £145/tCO_2 (£530/tC) under a 70% constraint and £215/tCO_2 (£790/tC) under an 80% constraint.
	UK Energy Research Centre (ERC) Energy Systems Modelling	From 2005-2007, UKERC-ESM has built comprehensive UK capacity in E4 (energy-economic-engineering-environment) modelling, including full and updated versions of the technology focused energy systems MARKAL and MARKAL-Macro models. This model has been used to address a range of UK energy policy issues including quantifying long-term carbon reductions targets, and the development of hydrogen infrastructures. International activities include the Japan-UK Low Carbon Societies research project.
United States	Brookhaven National Laboratory, U.S. Department of Energy	Application of the family of MARKAL models in a wide variety of areas. Most notably, to assess the merits of government R&D programs for various DOE offices including Energy Efficiency and Renewable Energy, Fossil, and Nuclear. Other applications include a local model of the New York City electric/heat sector, and the development of a multi-region US MARKAL model.
	U.S. Environmental Protection Agency [Office of Research and Development]	Development of a Regional U.S. MARKAL Database for Energy and Emissions Modeling under the auspices of the U.S. Climate Change Science Program (CCSP) (a collaborative effort among thirteen agencies of the U.S. federal government). From the CCSP's 2003 strategic plan, its mission is to "facilitate the creation and application of knowledge of the Earth's global environment through research, observations, decision support, and communication."
	The Northeast MARKAL (NE-MARKAL) Model: A Regional Energy/Economic Framework for the Northeast US	An integrated assessment framework has been developed around a 12-region MARKAL model tailored to represent 11 Northeast U.S. states and the District of Columbia. The model is being used to promote regional approaches to common issues, and examine specific policies of interest to individual states.
	Biomass Resources for Energy in Ohio	Analysis of the use of biomass energy for Ohio under different policy scenarios and presentation of the economic and environmental impacts with potential limitations that the state may face in the future.