ЕКОЛОГІЧНІ ТА ЕНЕРГЕТИЧНІ БАР'ЄРИ, СТІЙКІСТЬ ТА ДИНАМІКА ПЛАНЕТАРНОГО КЛІМАТУ

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CLIMATE CHANGE IMPACT IN ENERGY SYSTEM

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КЛІМАТИЧНІ ЗМІНИ З ПОГЛЯДУ ЕНЕРГЕТИЧНИХ СИСТЕМ

У статті виражена стурбованість поступовим підвищенням середньорічної температури планети і розглянуто питання про те, які зміни необхідно в зв'язку з цим внести в промислову енергетику в майбутньому. Висвітлено важливість використання «поновлюваних» джерел енергії, коректування політики країн у відношенні використання таких корисних копалин, як вугілля і нафта, контролю викидів CO_2. Проблеми енергетики майбутнього розглядаються з трьох точок зору: економічної, соціальної й охорони навколишнього середовища. Підкреслено необхідність змін у соціальній психології, підвищення відповідальності людства стосовно навколишнього середовища. Запропоновано імітаційні моделі фізичних, економічних і екологічних систем. Ці досить складні моделі призначені для передбачення глобальної динаміки клімату.

Ключові слова: економіко-математичне моделювання, охорона навколишнього середовища, контроль викиду CO_2, *глобальне потепління.*

1. INTRODUCTION

Energy in the 21st century faces unprecedent challenges: Global warming will be the biggest issue requiring structural and technical-economic changes to energy system.

If when they started the works of the Protocol Kyoto the international debate rotated around the science of the climate and to the commitments of contention of the emissions, in recent years the themes of the climatic change are connected directly with the world energy system. Structural transformations in the energy production, diversification of fuels, efficacy and traffic of the internal use of coal and derived from the petroleum toward renewable energies they are included in the measures in motion or in study. We can not forget the increase of the emissions predicted for the future related to the growth of the energy consumption in developing countries, above all the Chinese and Indian colossuses.

The sustainable development in the energy perspective has extensive and deep relations in the three dimensions of the sustainability: economic, social and environmental.

They are three the factors that condition the sustainability of our energy model: the availability of the resources to face the demand of energy, the environmental impact caused by the sources utilized for their supply and consumption, and the enormous lack of equity in the access to this indispensable element for the human development currently.

The existence of environmental impacts in the production and use of the energy has been observed since time ago. The deforestation of many areas or the associated contamination to the industrial processes are well known cases. But although serious was a matter of local impacts. In the last a hundred years the local effects have passed to be global threats.

The combustion of fossil fuels carries associate a considered environmental impact, gives origin fundamentally to emissions of CO_2 causing the effect greenhouse.

Climate change is arguably one of the greatest environmental threats the world is facing. The impacts of disruption change leading to catastrophic events such as storms, droughts, sea level rise and floods are already being felt across the world.

The mitigation of these adverse environmental impacts due to climate change requires the reduction of carbon dioxide emission from the energy sector, the dominant source of global greenhouse gas emissions

In this sense the ratification of the Protocol of Kyoto February 16, 2005 marks the beginning of a new times. It is the first legally binding global Treaty of ecological character and the most ambitious one agreed to protect the environment and to face the greenhouse effect gases that cause the climatic change.

Currently all the studies relate to climatic change utilize as tool different integrated models (IM from now on) of energy and economic-environmental.

The IM are like any model, representations simplified of the real systems. These models are complex tools that try to simulate the real systems physical, environmental and economic and they are very valuable to experience results under different conditions or settings.

All these models by their complexity, diligence and dynamic calculations to carry out are processed in computer under different determining data of entrance, that can change under possible associate-political disruptions that they can be determined in the setting of departure, forming some dynamic systems of very powerful analysis to predict the final results. These results are images or representations alternatives of how the future would be able to be developed and the main role is to offer the agents with being able of decision the possibility of identifying problems, threats and opportunities.

In current studies, the researchers consider different scenarios o simulations in the IM. The most common and representative for our purpose are the follows:

– Reference scenario or BAU (Business as usual): Case of no policy-intervention for global warming mitigations. No limitations of emissions of CO_2.

– 550 ppmv Stabilization or Base Case: CO_2 constraint is to keep atmospheric CO_2 concentration less than 550ppm. The concentration of 550 ppmv corresponds to the double of the pre-industrial revolution level (about 275 ppmv), though the desirable level is still unknown. This target is, however, the modest one because the mitigation costs increase drastically for the stabilization target below 550 ppmv.

– Scenarios with different technological options to store CO_2 .

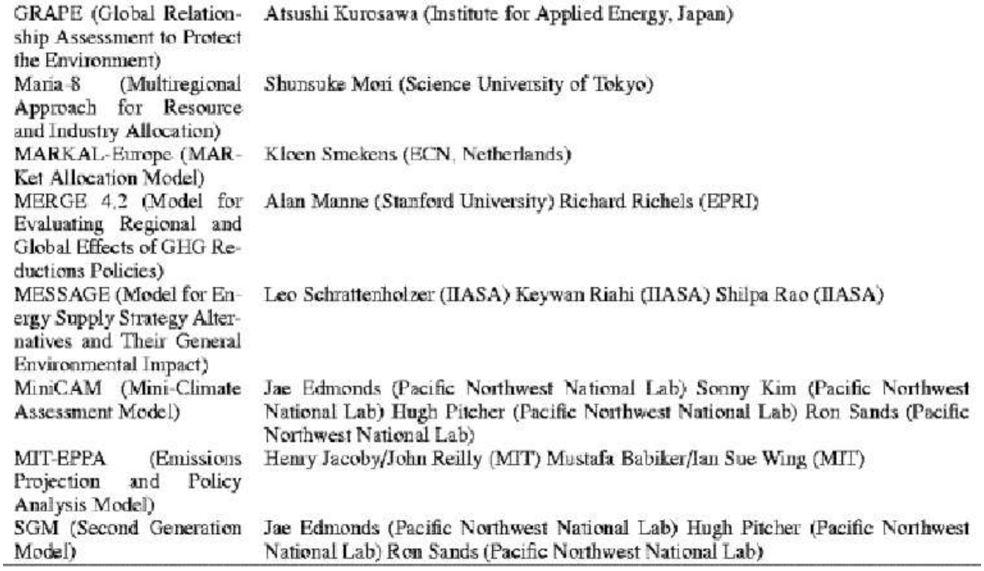
This simulations however have the following uncertainties in tackling the global warming issue:

– Options for CO_2 storage: Reductions in CO_2 emissions will be achieved by the combination of energy conservation, shift to less carbon-intensive fuels, and CO_2 separation, recovery, and storage. CO_2 storage also has several options, but some of them are still in the process of scientific assessment, so future availability is uncertain.

– Concentration of atmospheric CO_2: the target level of concentration of atmospheric CO_2 is uncertain.

Numerous IM exists, we can cite as the most representative the ones that utilize the experts of the EMF (Energy Modeling Forum) 19 study in the university of Stanford:

ABARE-GTEM (Global Trade and Environment Model)	Brian Fisher/Vivek Tulpule/Darren Kennedy/Steve Brown (ABARE)
AIM (Asia Integrated Model)	T. Morita, M.Kainuma (NIES, Japan) Yuzuri Matsuoka (Kyoto University)
AMIGA (All Modular Industry Growth Assessment)	Don Hanson (Argonne National Laboratory)
(DNE21) (Dynamic New Earth 21)	Kenji Yamaji/Yasumasa Fujii (University of Tokyo) Keigo Akimoto (RITE)
FUND (Climate Framework for Uncertainty, Negotiation, and Distribution)	Richard Tol (Vrije Universiteit Amsterdam)



GRAPE (Global Relationship Assessment to Protect the Environment)	Atsushi Kurosawa (Institute for Applied Energy, Japan)
Maria-8 (Multiregional Approach for Resource and Industry Allocation)	Shunsuke Mori (Science University of Tokyo)
MARKAL-Europe (MARKet Allocation Model)	Kloen Smekens (ECN, Netherlands)
MERGE 4.2 (Model for Evaluating Regional and Global Effects of GHG Reductions Policies)	Alan Manne (Stanford University) Richard Richels (EPRI)
MESSAGE (Model for Energy Supply Strategy Alternatives and Their General Environmental Impact)	Leo Schrattenholzer (IIASA) Keywan Riahi (IIASA) Shilpa Rao (IIASA)
MiniCAM (Mini-Climate Assessment Model)	Jae Edmonds (Pacific Northwest National Lab) Sonny Kim (Pacific Northwest National Lab) Hugh Pitcher (Pacific Northwest National Lab) Ron Sands (Pacific Northwest National Lab)
MIT-EPPA (Emissions Projection and Policy Analysis Model)	Henry Jacoby/John Reilly (MIT) Mustafa Babiker/Ian Sue Wing (MIT)
SGM (Second Generation Model)	Jae Edmonds (Pacific Northwest National Lab) Hugh Pitcher (Pacific Northwest National Lab) Ron Sands (Pacific Northwest National Lab)

The model DNE21 (Dynamic New Earth 21) has currently a greater impact of citations and is the one that more is utilized in long-term energy systems simulations, evaluating the different technological options to mitigate the global warming.

The purpose of this article is to analyze the most significant results of different simulations carried out by different teams of researchers base on model DNE21, under different scenarios or cases. This will allow to make conclusions on the future development of the energy system.

The scenarios that have been considered and chosen of the bibliography, are the following:

Case 1: Reference scenario or BAU (Business as usual): Case of no policy-intervention for global warming mitigations. No limitations of emissions of CO_2.

Case 2: 550ppmv Stabilization or Base Case: CO_2 constraint is to keep atmospheric CO_2 concentration less than 550ppm. No prohibitions in any options to store CO_2.

DNE21 incorporates the following options to store CO_2:

§ EOR: injection into oil fields for use in enhanced oil recovery (EOR) systems.

§ Gas well injection: injection into exhausted natural gas wells,

§ Aquifer: injection into underground aquifers, and

§ Ocean: ocean storage (dissolution in seawater or storage in the deep seabed).

Among these options, EOR and gas well injections are already in practical use. Aquifer and Ocean sequestration, however, are still in the stage of scientific assessment. Researching studies do not deny the potential of their availability in the future, but should be cautions about their impact on enegy systems in the analysis.

To understand how these options will affect the role of the energy in the future, we have chosen from the bibliographic the three following cases:

Case 3 “CO_2: Ban of ocean”: This case prohibits storing CO_2 in the ocean. Other options are available. Ocean sequestration has a potential to store huge amount of CO_2 at a reasonable cost. However, the impact on the ocean environment is not clear.

Case 4 “CO_2:Ban of ocean and aquifer”: This case prohibits storing CO_2 into aquifer in addition to the restriction of case 3.

Case 5 “CO_2: Storage Prohibited”: This case does not allow any of the four options for storing CO_2. This is a radical case, but may provide insights on new energy systems.

2. BRIEF DESCRIPTION MODEL DNE21

The Dynamic New Earth 21 (DNE21) model has been developed by Professor Kenji Yamaji and Professor Yasumasa Fuji (The University of Tokyo). The aim is to assess technology options to mitigate global warming.

The Integrated Assessment Model DNE21 basically seeks the optimal trajectory of global energy systems development for the global warming mitigation by maximizing the cumulative discounted present value of the world macro economic consumption over the given time range. This model consists of three sub-models: an energy systems model, a macro economic model and a climate model (see Fig. 1).

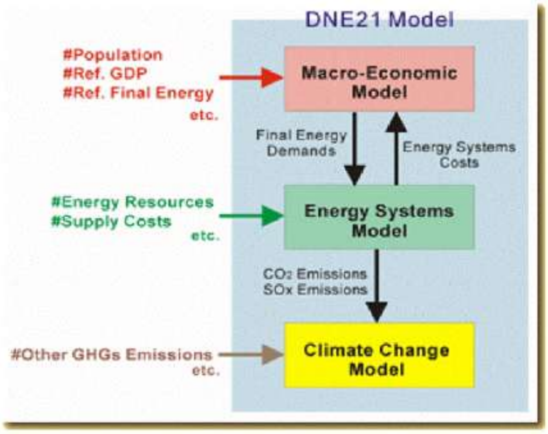


Fig. 1. **An overview of the integrated assessment model DNE21**

The model covers the time range over the 21st century with the representative time points of 2000, 2010, 2020, 2030, 2040, 2050, 2075 and 2100, and is formulated as a multi-region model, and the whole world is geopolitically divided into 10 regions: (1) North America, (2) Western Europe, (3) Japan, (4) Oceania, (5) Centrally Planned Economy Asia, (6) South and East Asia, (7) Middle East and Northern Africa, (8) Subsaharan and Southern Africa, (9) Latin America and (10) Former USSR and Eastern Europe.

Under exogenously projected scenarios of reference energy demand, the Dynamic New Earth 21 model seeks the optimal development path for the future world energy system at 10-year intervals up to the year 2100, contributing to short-term decision making, but at the same time keeping a long-term perspectives.

The characteristics of this model in which refers to its principal sub-model the energy one, incorporates all the fuels and energies transformation technologies as well as the potential development of abatements CO_2 technologies refer to CO_2 separation, recovery, and storage. Fig 2 shows a simplification of this sub-model

DNE21 is integrated with MAGICC (Model for the Assessment of Greenhouse gas Induced Climate Change) model to depict scenarios under the different constraint of CO_2 atmospheric concentration and global averaged surface temperature.

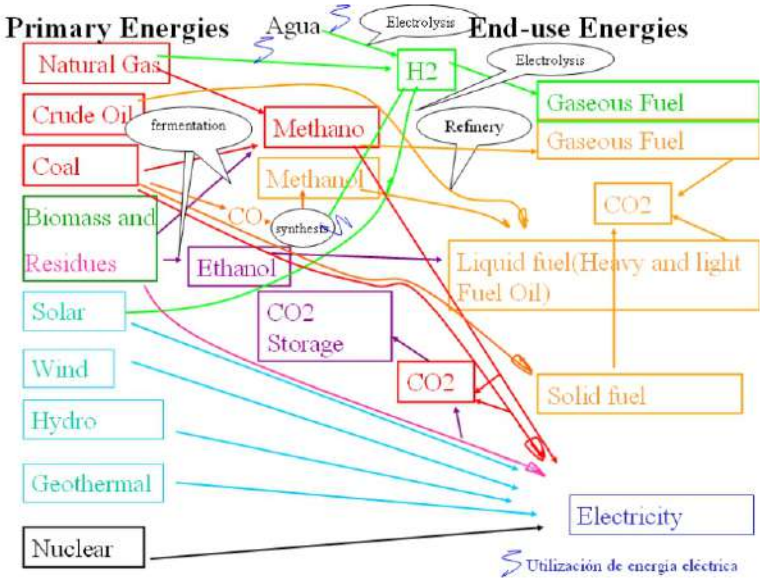
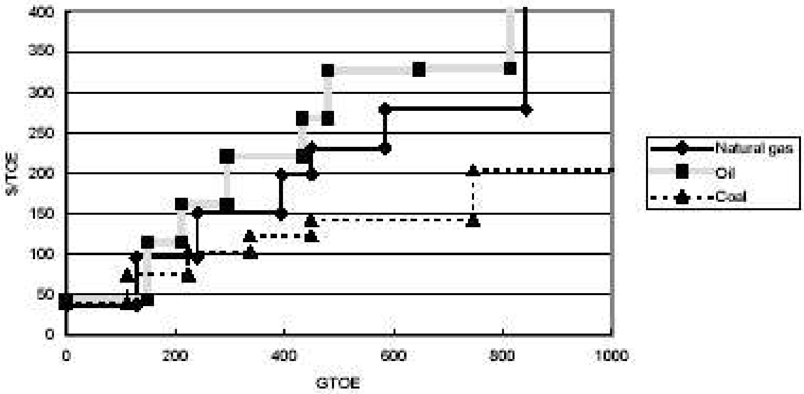


Fig. 2. **Energy system simplificated**



GTOE: Gigatons of oil equivalent

Fig.3: Supply curves for world fossil fuel resources

3. MODEL ASSUMPTIONS

As can be imagined from the energy flow diagram shown in Fig. 2, DNE21 contains many variables to be set. This chapter shows the following key assumptions:

- Assumptions on primary energy potential costs.
- Assumptions on technologies.
- Population, GDP and final energy demands.

3.1. Assumed primary energy potentials and costs

Assumed fossil fuel resources and production costs are derived from the estimations by Rogner (1997). The amounts of the world conventional and unconventional oil resources are about 300 and 2340 Gtoe, respectively. Those of world conventional and unconventional natural gas resources are about 390 and 19,590 Gtoe, respectively. The unconventional gas includes methane hydrate resource. However, none of our model simulation results call for methane hydrates before 2100 in this study. Fig. 3 shows the fossil fuel production costs for the entire world.

Table 1 shows the assumed unit supply costs and world annual supply potential of renewable energy (e.g., Nakicenovic, 1993). The supply costs of hydro and geothermal, wind power and photovoltaics are expressed as nonlinear functions of their annual production amounts for each of the regions. The biomass energy potentials of 13 types are estimated with a spreadsheet model which is a simplified form of GLUE Model (Global Land Use and Energy Model; Yamamoto and Yamaji, 1997).

Table 1

Assumed unit supply costs and world annual supply potential of renewable energy

	Unit supply costs	World annual production potential
Hydro and geothermal	10–180 ($\mathrm{US}_{1990}\$/\mathrm{MWh}$)^{a}	15000 (TWh/year)
Wind power	70–340 ($\mathrm{US}_{1990}\$/\mathrm{MWh}$)$^{a\ b}$	7900 (TWh/year)
Photovoltaics	180–361 ($\mathrm{US}_{1990}\$/\mathrm{MWh}$)^{cd}	286,400 (TWh/year)
Biomass (plantation)	120–1200 ($\mathrm{US}_{1990}\$/\mathrm{toe}$)^{e}	1300–4400 (Mtoe/year)^{f}
Biomass (residues)	−550–390 ($\mathrm{US}_{1990}\$/\mathrm{toe}$)^{e}	2100–5800 (Mtoe/year)^{f}

3.2. Assumptions on technologies

3.2.1. Electricity generation

The assumed parameters on electricity generation such as unit plant costs, annual expense rates, usage rates and conversion efficiencies are shown in Table 2 (e.g., OECD/IEA, 1998 and Ishitani and Johansson, 1996). The upper limit is placed on the nuclear power capacity of each region, paying due consideration to the public acceptance issue. The upper limit of the world total is 920 GW in 2050 and 1450 GW in 2100.

3.2.2. CO_2 recovery and sequestration

CO_2 recovery parameters, i. e., unit costs of CO_2 recovery plants and required energy consumption are assumed as in Table 3 (e. g., Steinberg and Cheng, 1984), and costs and capacities of CO_2 sequestration are assumed as in Table 4 (e.g., Ishitani et al., 1993).

3.3. Population, GDP and final energy demands

Future scenarios of population, reference GDP and reference final energy demands are derived from B2 Marker Scenario of IPCC SRES (Nakicenovic et al., 2000 and UN, 1998).Some modifications on the original scenario data are made so as to keep consistency with the historical data (IEA, 2001a; IEA, 2001b and World Bank, 2001) and with DNE21 region division. Fig. 4 shows the procedure to generate assumed data of the population, reference GDP and reference final energy demands of four kinds of fuels, where the growth rates are utilized rather than the absolute values of the SRES scenario data. The assumed reference GDP by region and reference final energy demands by fuel are shown in Fig. 5 and Fig. 6, respectively. On this assumption, the world population reaches 10.4 billion in 2100, the gross world product reaches 217 trillion US_{1990}\$/year and the world final energy demands 19.7 Gtoe/year.

4. MODEL SIMULATION RESULTS

In this section the simulation results that have obtained the authors of the model are exposed under the scenarios described previously.

The most significant results are the following:

1) Primary energy production. Fig. 7. shows the evolution of this production for the reference case or Bau and the Base or 550 ppmv sta

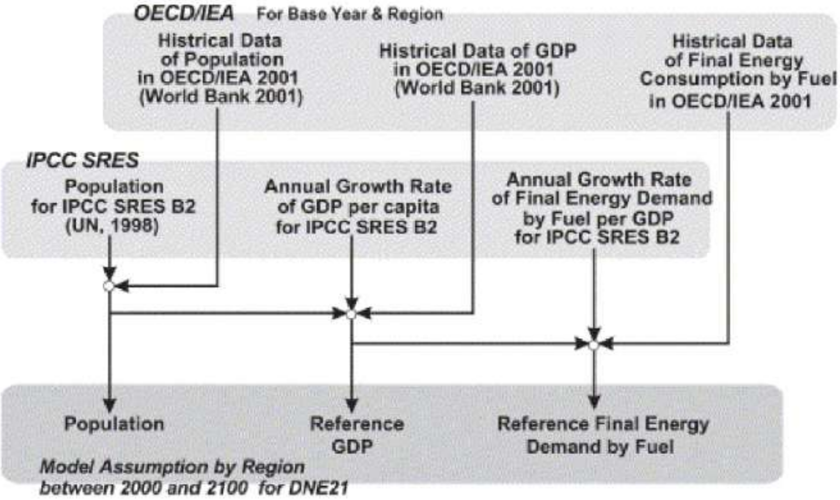
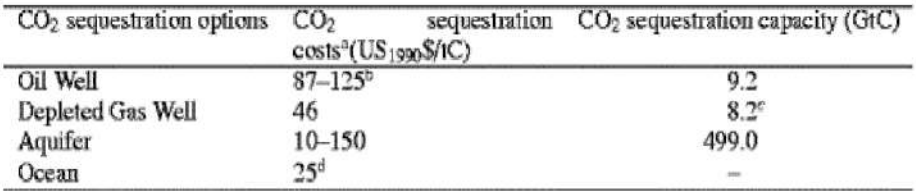


Fig 4. **Procedure to generate assumed data of population, referente GDP and referente final energy demand**

Table 4

Assumptions for CO_2 sequestrations



CO_2 sequestration options	CO_2 sequestration costs[a](US$_{1990}$$/tC)	CO_2 sequestration capacity (GtC)
Oil Well	87–125[b]	9.2
Depleted Gas Well	46	8.2[c]
Aquifer	10–150	499.0
Ocean	25[d]	–

3) Contributions of technological options to the reduction of CO_2 emissions from BAU (reference) to BASE (550 ppmv)

Figura 10 implies the following:

§ CO_2 reductions cannot be easily settled by any single technological option considered here. However, this results shows that if all types of technological options are reasonable integrated with one another, a significant CO_2 emission reduction potential exists to limit atmospheric CO_2 concentration to 550 ppm by the end of the 21st century.

§ Looking at the net emissions, the optimal CO_2 emission trajectory indicates relatively modest abatement actions are expected, especially in the near future, allowing global CO_2 emissions to continue rise until around the middle of the 21st century. The implication here is that immediate CO_2 emission reduction or emission stabilization strategies will not necessarily lead to economically efficient outcomes. This partly because we can certainly anticipate significant improvements in both the technological and economic performances of CO_2 abatement actions.

4) PIB

The world GDP loss in the 550 ppmv Stabilization Case from in the Reference Case would be about 3% (the maximum between 2000 and 2100).

5) Final energy consumption

This Figure shows a reduction 24 % of final energy consumption in the Base case.

6) Global mean temperature change

The temperature of about 1.0 degrees C decreases in 2100 from in the Reference Case to in the 550 ppmv Stabilization Case.

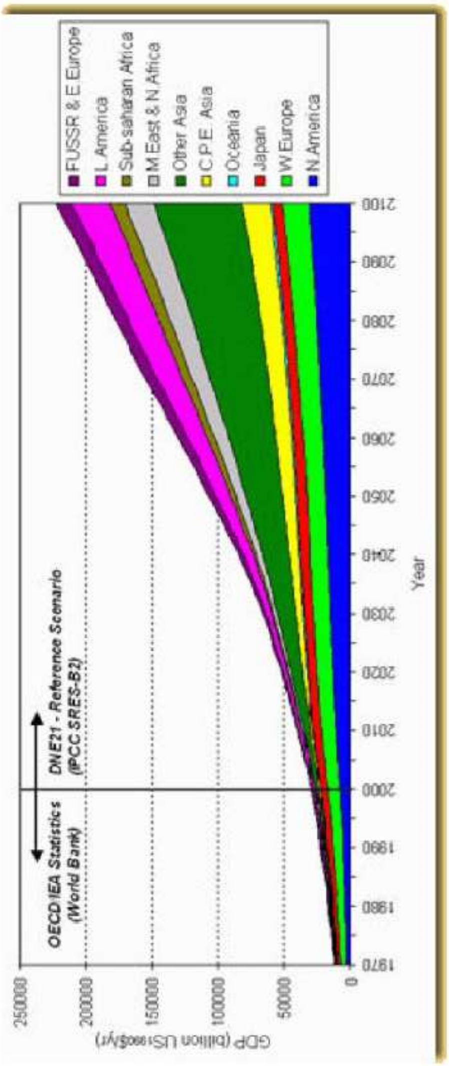


Fig 5. **Assumed referente GDP**

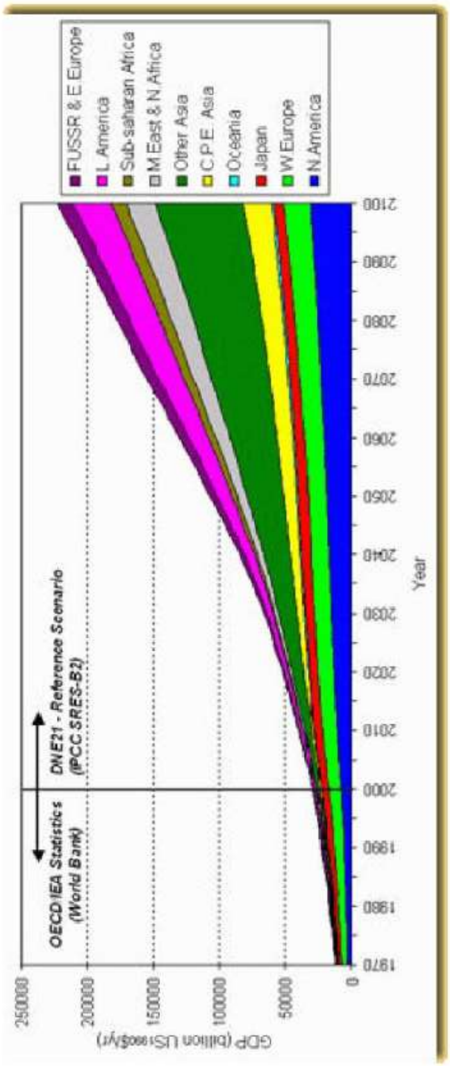


Fig. 6. **Assumed reference final energy demands**

7) Sea level change

The sea level rise in 2100 is calculated to be about 40 cm (relative to in 1990) in the 550 ppmv Stabilization Case and is about 10 cm lower than in the Reference Case.

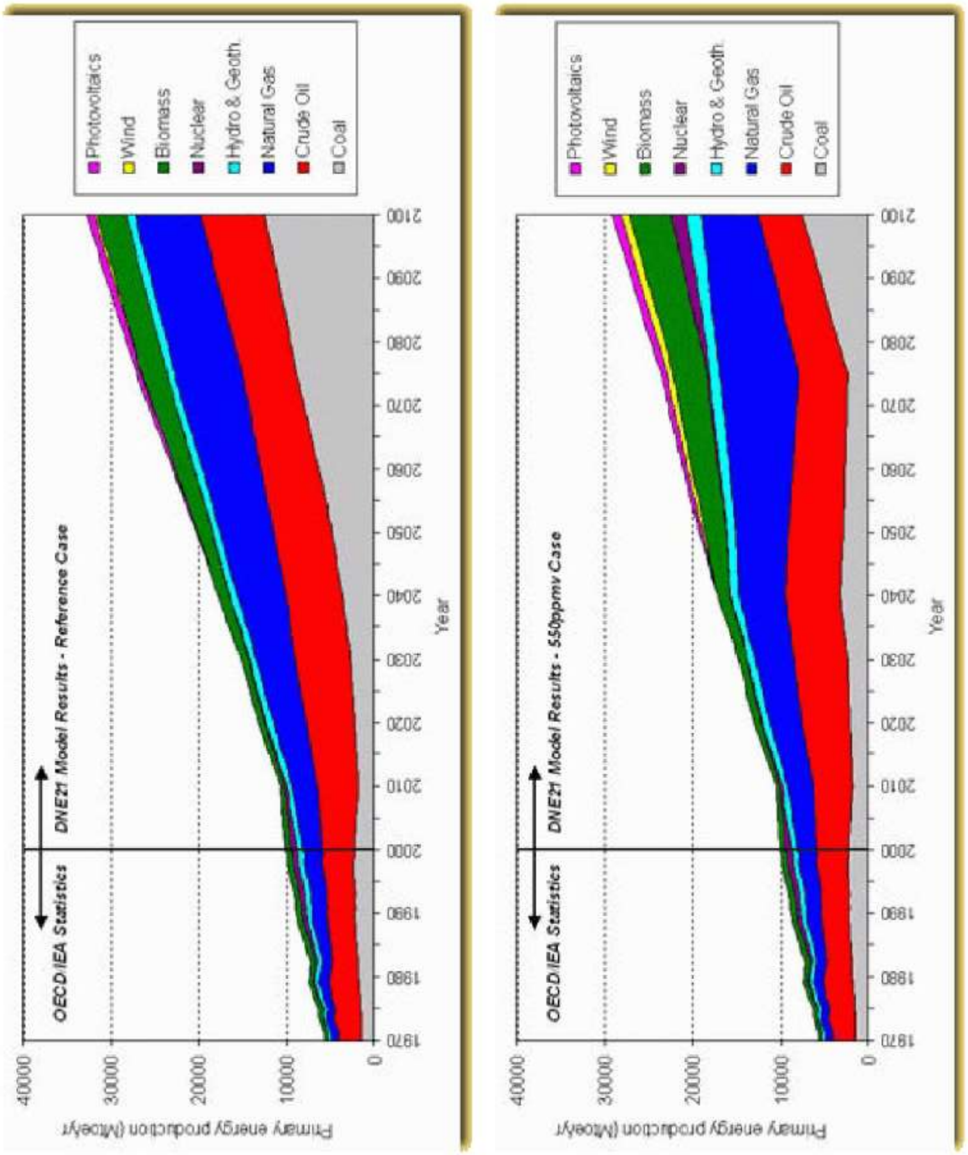
8) CO$_2$ shadow price (marginal CO$_2$ emission reduction cost)

CO2 shadow price is the cost to reduce the additional unit CO2 emission in the target time point, and corresponds to the marginal CO2 emission reduction cost. The shadow price also corresponds to the theoretical carbon tax rate. The prices in 2010 and 2100 are calculated to be about 5 and 450 US1990$/tC, respectively.

9) Transitions of shares of world primary energy supply for the Base Case

These case Base results are obtained without any prohibitions in the options to store CO$_2$. There are several conclusions we can make from the Fig.9:

§ The role of coal keeps strong across the century. Anyway this role of coal seems to show slightly strange behaviour in declining in the first half of century, then increasing in the latter half of the century. This phenomenon is explained as below. In the first half of the century, the roal of coal is limited because it emits lots of CO$_2$. In the latter half of the century, however, the CO$_2$ sequestration becomes competitive, and IGCC (Integrated coal Gasification Combined



BAU

BASE

Fig. 7. **Primary energy production**

Cycle) with CO_2 sequestration may change the role of coal. It may pave a way for coal to play certain role to mitigate global warming.

§ Gas utilization increases across the century.

§ The oil declines and is replacing by gas.

§ The renewable energies and nuclear increase their role in the latter half of the century. The role of each renewable energy is not so big, but together such energies will attain third position late in the century.

The changes in the types of hydrocarbons are turned out of the economic study of the model, keeping in mind the marginal prices of the CO2 and of the evolution of the different technologies.

If we refer to nuclear energy, we can say that although the technical power in reducing CO_2 emissions is huge, many uncertain factors, such as the difficulty of obtaining public acceptance and concerns about nuclear waste and weapon proliferation, make its future prospects less clear. The DNE21 assumes upper limits on the maximum capacities of nuclear power plants.

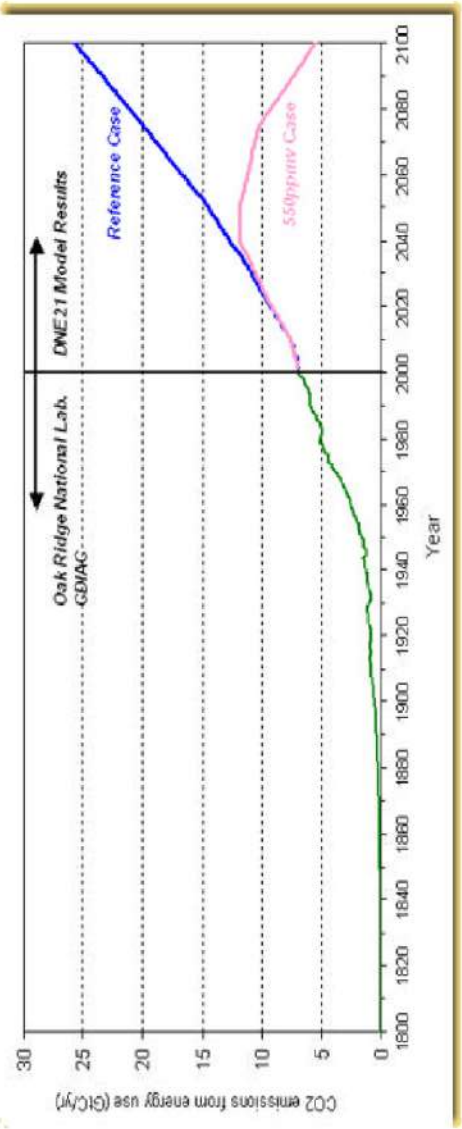


Fig. 8. **CO_2 emissions**

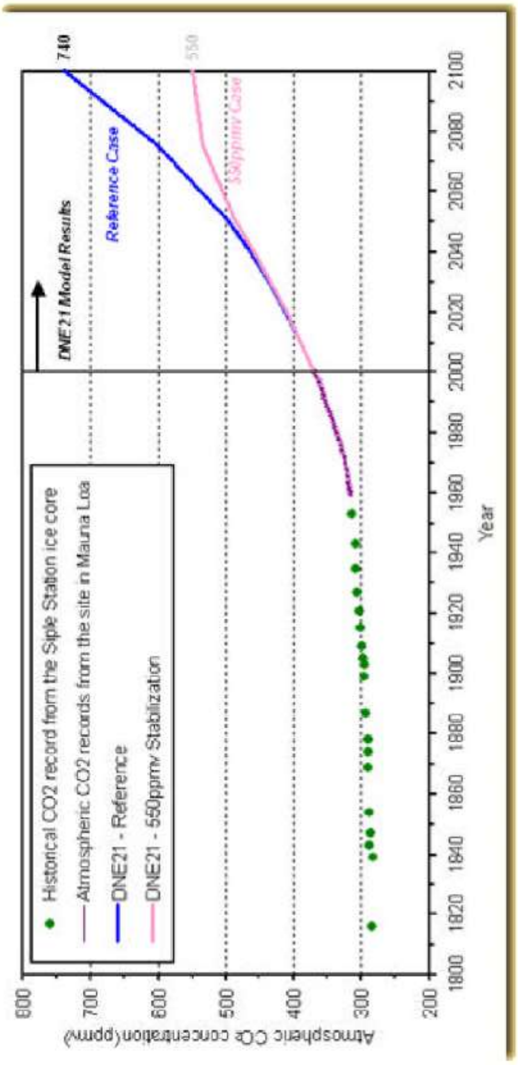


Fig. 9 **atmospheric CO_2 concentration**

Currently the four options for CO_2 storage are not being used. To contemplate the different situations of the development of these technologies, it is necessary to analyze the following cases:

Case 3 “CO_2: Ban of ocean”: This case prohibits storing CO_2 in the ocean Ocean sequestration has a potential to store huge amount of CO_2 at a reasonable cost. However, the impact on the ocean environment is not clear. For that reason we consider high its probability of occurrence.

Case 4 “CO_2:Ban of ocean and aquifer”: This case prohibits storing CO_2 into aquifer in addition to the restriction of case 3. Aquifer sequestration is less cost-effective than ocean but with less environment impact This scenario allows EOR and gas well injection, technological options more expensives and therefore their utilization will cause marginal cost CO_2 larger.

Case 5 "CO_2: Storage Prohibited": This case does not allow any of the four options for storing CO_2. This is a radical case, but may provide insights on new energy systems.

Fig 17 shows the primary energy productions of those three cases with the "Base" case. Fig.18 shows the contribution of each technological option to the reduction of CO_2 emissions of those three cases along with the "Base" case.

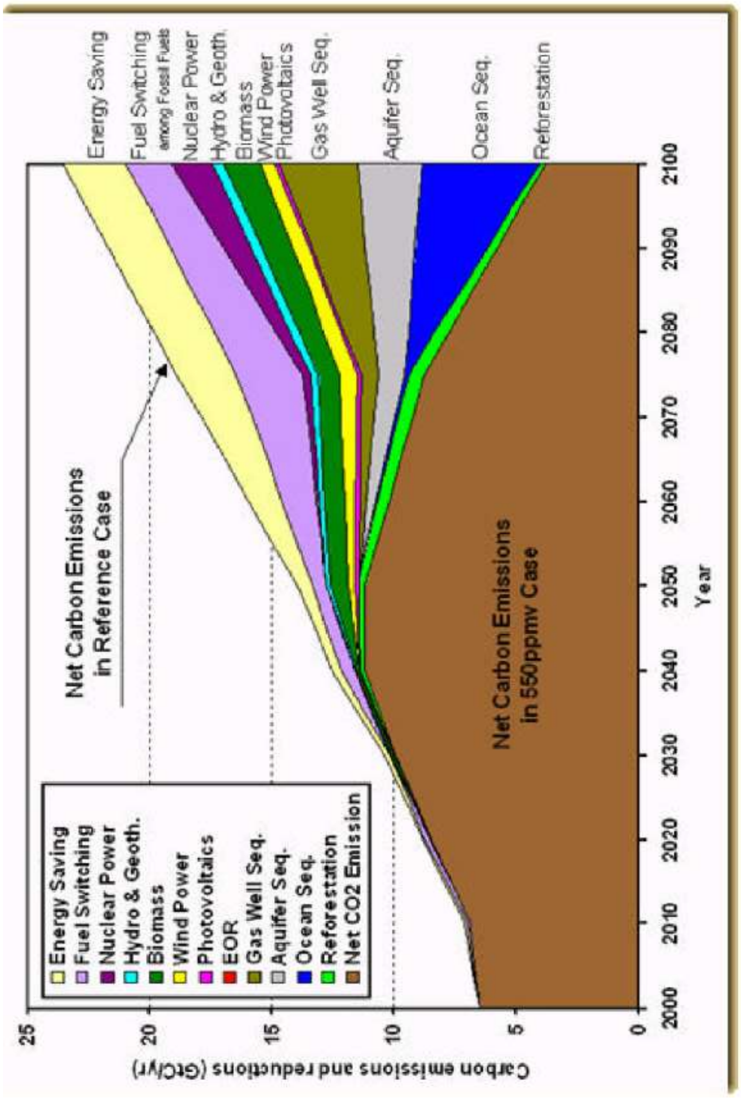


Fig 10: **Contributions of technological options to the reduction of CO_2 emissions from the BAU to "Base"**

Outlook of the future energy mix

§ Restriction of CO_2 storage options (but not prohibitions) promote fuel switching. One characteristic here is that such a fuel switch means a shift to natural gas.

§ When no storage option is available, the role of natural gas decline and photovoltaics increase the share.

§ The roal of coal, on the other hand, declines as the options for CO_2 storage are narrowed. This means that selecting coal is a risky option when the availability of CO_2 storage is uncertain.

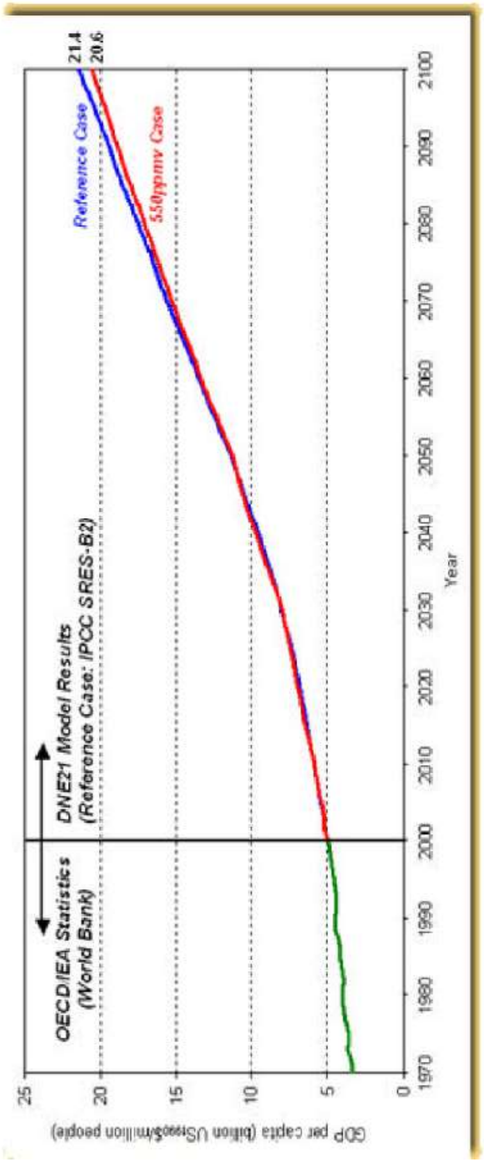


Fig 11: **PIB**

Outlook of the contribution of each technological option to the reduction of CO_2 emissions

Narrow the options for CO_2 storage enhances the contribution of renewables (specially photovoltaics) and nuclear energy to reducing CO_2.

5. CONCLUDING REMARKS

The simulation results with this model indicate that the 550 ppmv Stabilization Case can be achieved without severe economic losses. The optimun carbon emisiyn strategy is a combination of acceptance of a slight lowering in GDP growht, energy saving in end-use sectors, fuel switching and CO_2 sequestration. Continuous development of better technologies for energy saving are required all throught the 21st century. CO_2 sequestration technologies are one of the most important technologies after the middle of this century for 550ppmv stabilization.

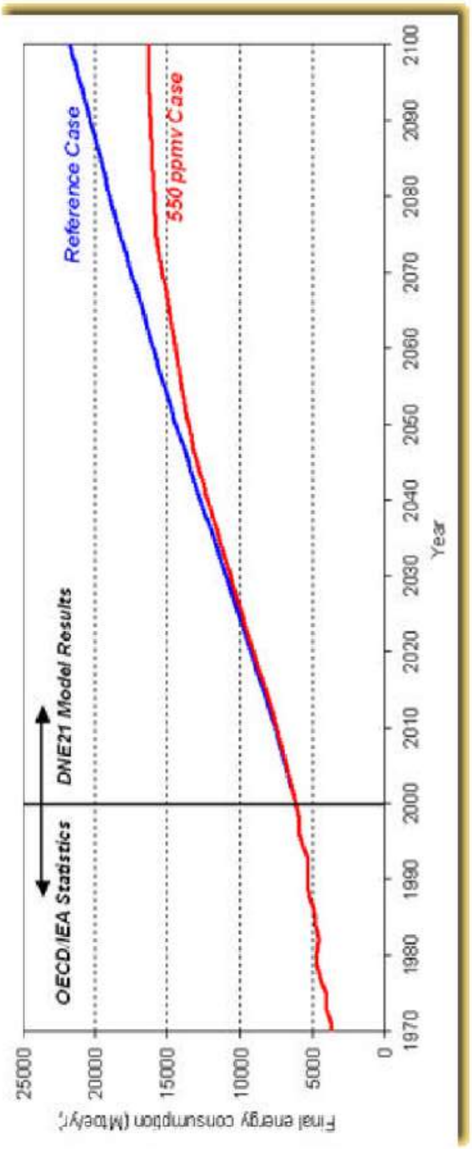


Fig 12: **Final energy consumption**

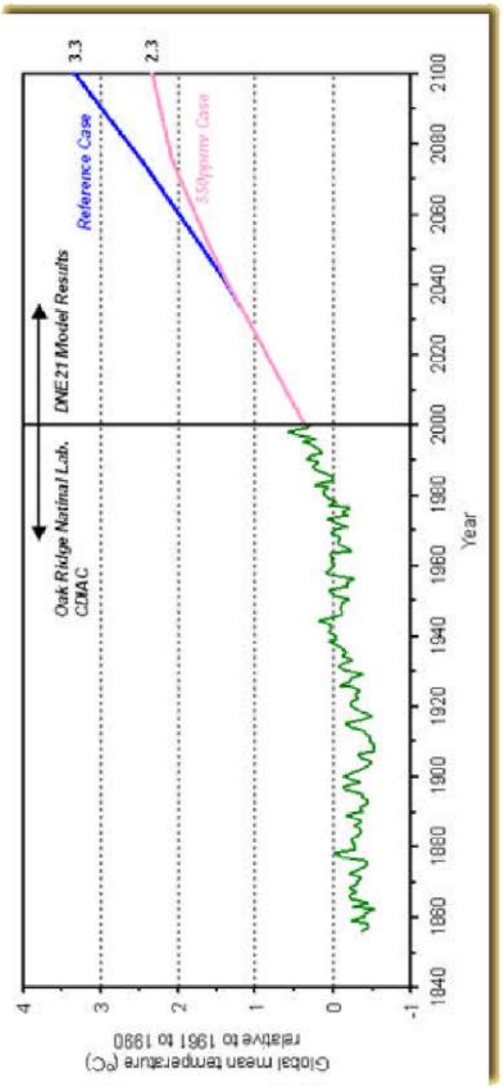


Fig 13: **Global mean temperature change**

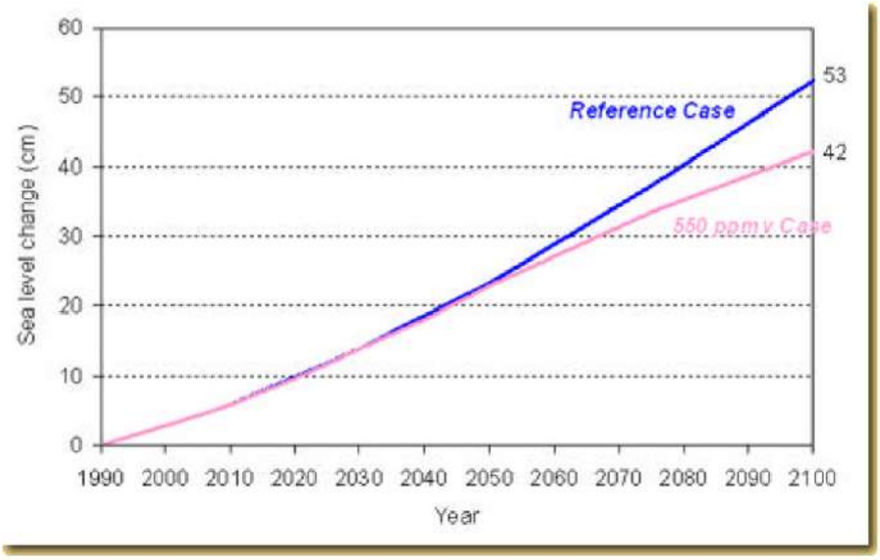


Fig 14: **Global mean temperature change**

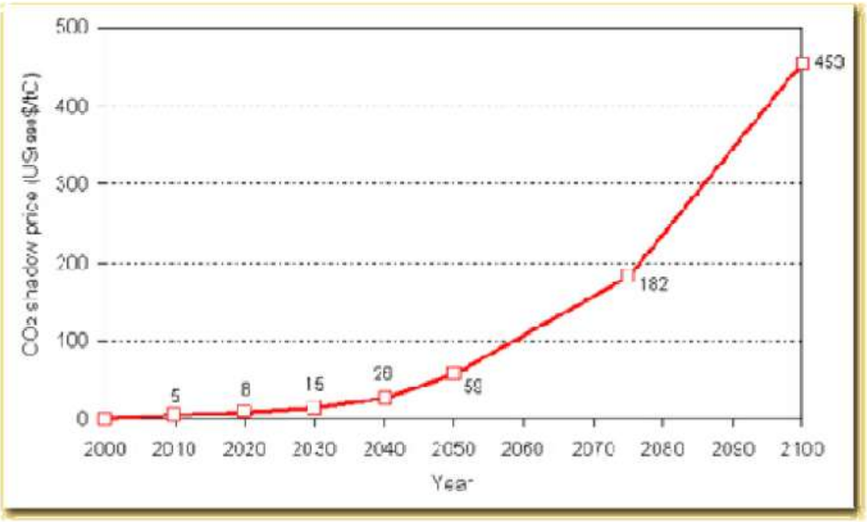


Fig 15: **CO_2 shadow price**

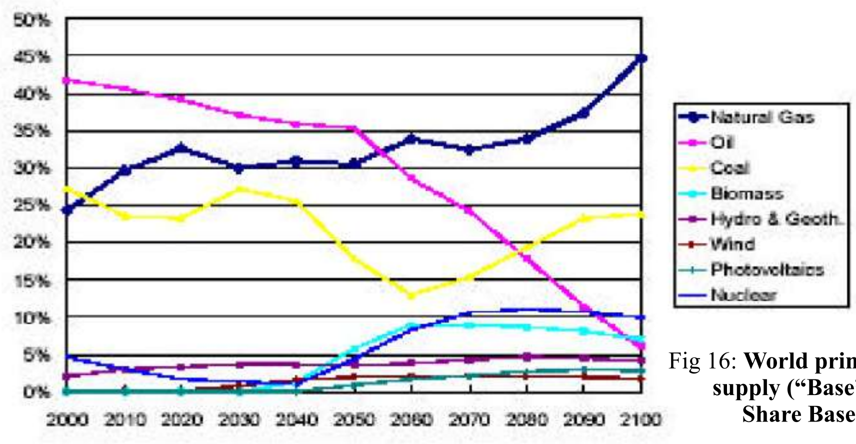
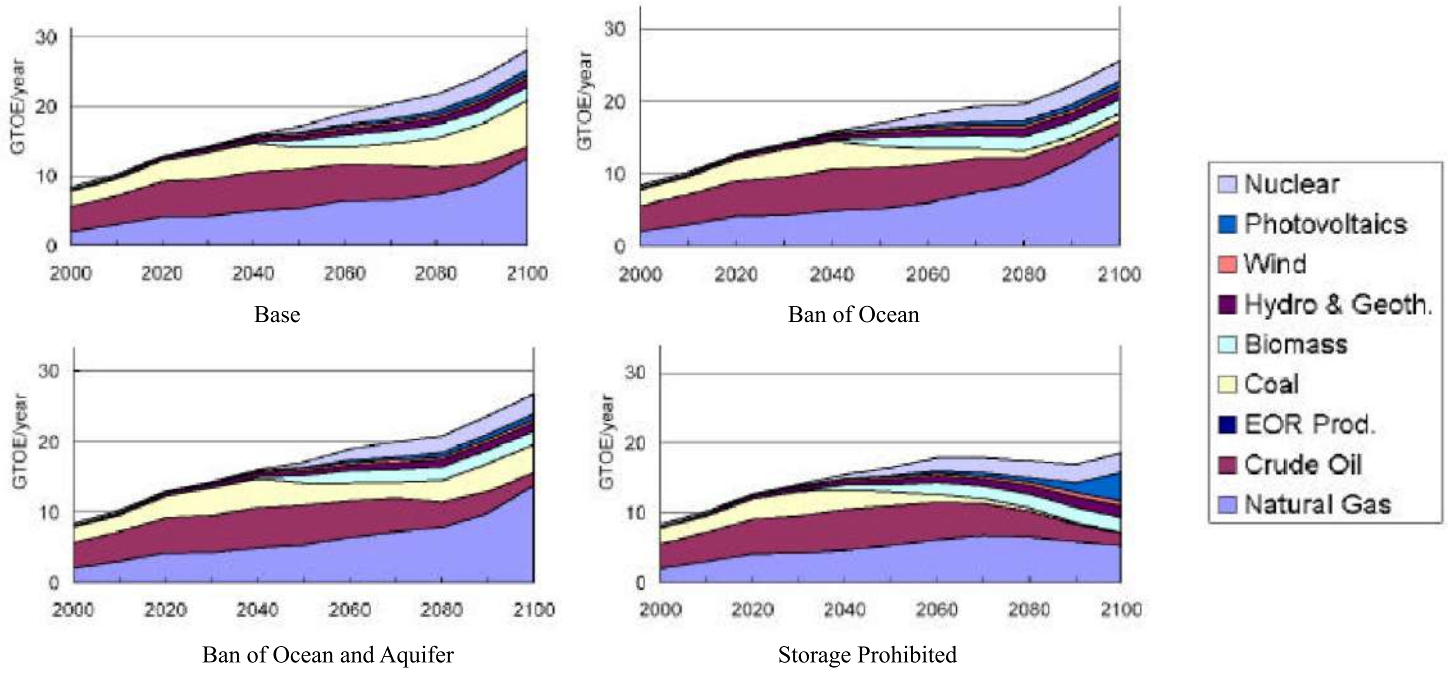


Fig 16: **World primary energy supply (“Base” case): Share Base (%)**



Base

Ban of Ocean

Ban of Ocean and Aquifer

Storage Prohibited

Fig. 17 **Primary energy production for different cases**

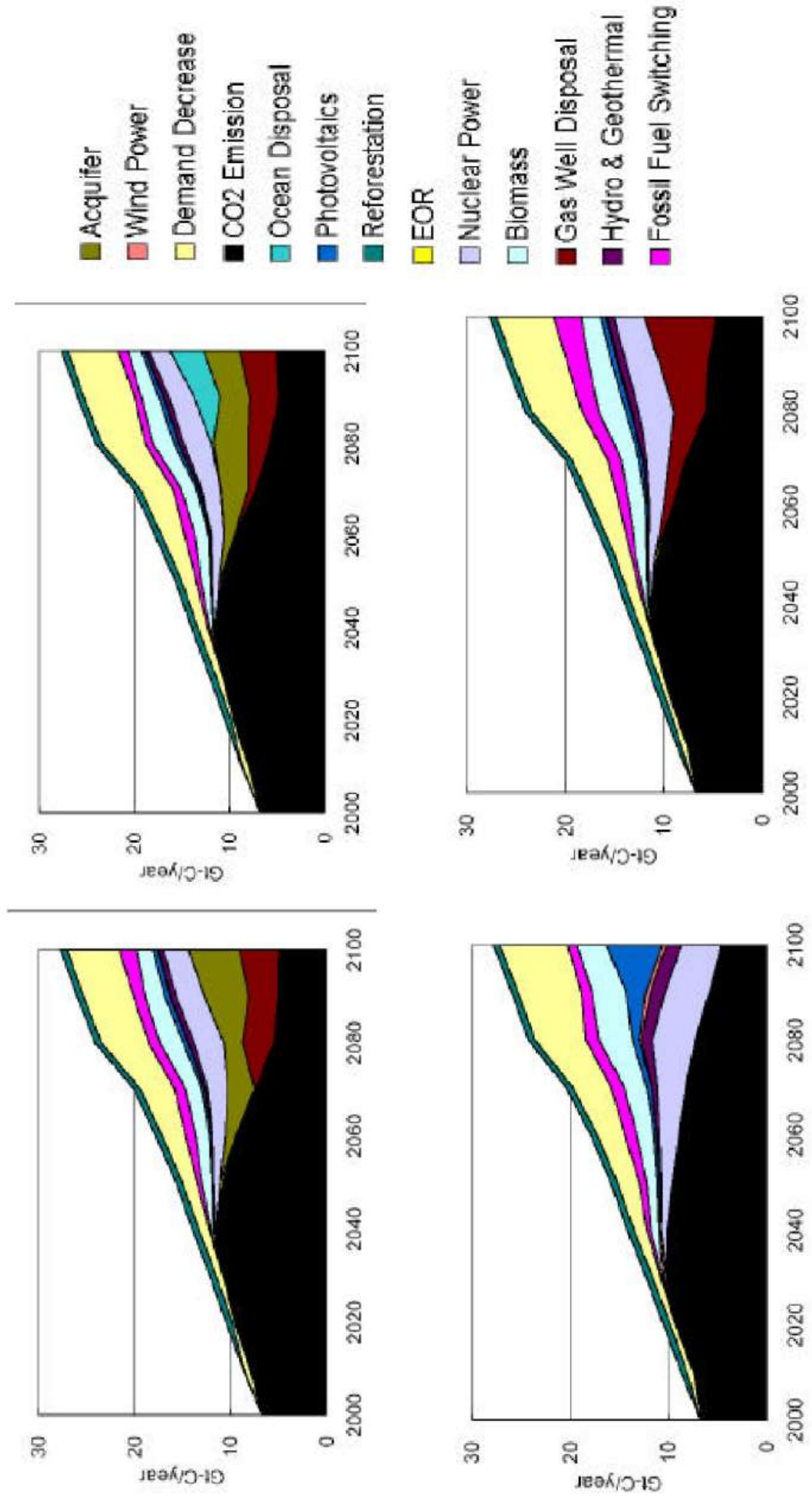


Fig 18: **Contributions of technological options to the reduction of CO_2 emissions**

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