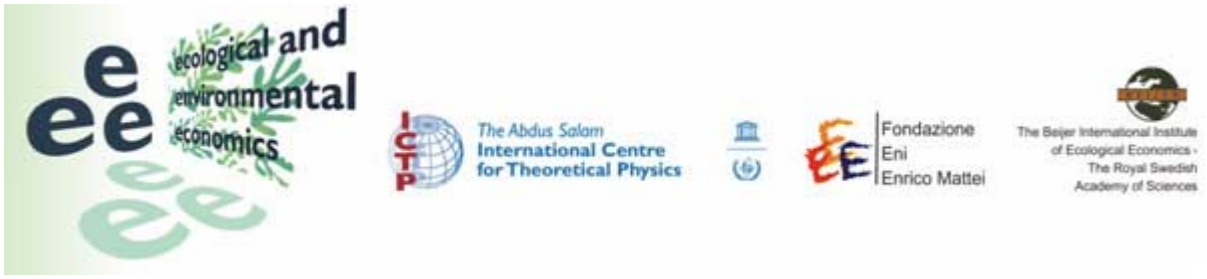

3rd International Workshop on

INTEGRATED CLIMATE MODELS:
AN INTERDISCIPLINARY ASSESSMENT OF
CLIMATE IMPACTS AND POLICIES

12-13 January 2006
ICTP, Trieste, Italy

LONG-TERM TARGET OF GLOBAL WARMING MITIGATION AND INTEGRATED ASSESSMENT

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Research Institute of Innovative Technology for the Earth – RITE
Japan

smr 1681

3rd International Workshop on Integrated Climate Models: An interdisciplinary assessment of climate impacts and policies

Long-term Target of GWM and Integrated Assessment

Jan. 12-13, 2006

GWM; Global Warming Mitigation

Institute of Innovative Technology for the Earth (RITE)
Systems Analysis Group
Toshimasa Tomoda

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1. Introduction to an IAM, DNE21 and some analysis results
2. Limitations of analyses with IAMs
   - What UNFCCC Articles 2 and 3 say
   - Large regional differences of warming damages
   - Existence of catastrophic impacts
   - Difficulty with monetary evaluation of all kinds of damages
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More attention to warming impacts
- Catastrophic events to be prevented regardless of costs
- Regional differences to be given full consideration
- Damages to be evaluated not necessarily in money

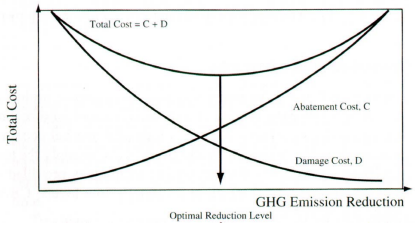
Warming mitigation measures and costs
- Assessed for possibly impact-tolerable emission paths

4. Concluding remarks

Introduction to an IAM, DNE21 and some analysis results

Principle of IAM Analysis

- Emission reduction level is determined so that the sum of damage cost and abatement cost is minimized, on a condition that all the warming damages can be evaluated in money.



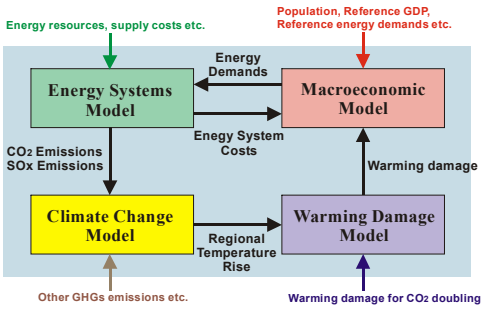
Ref. IPCC WGIII SAR

Outline of Integrated Assessment Model DNE21

- Integration of 4 models:
  - energy systems model
  - macro-economic model,
  - climate change model, and
  - warming damage model
- Inter-temporal non-linear optimization model (maximization of consumption (= production - investment - energy system costs - warming damage))
- 10 region division of the world
- Time horizon: 2000-2100

DNE: Dynamic New Earth

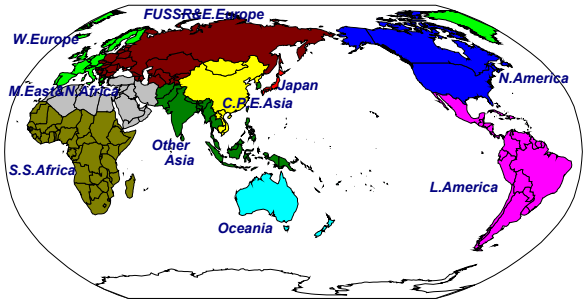
Structure of Integrated Assessment Model DNE21



The four models are hard-linked.

Geological Coverage of DNE21 Model

- 10 World Regions -



Outline of the Energy Systems Model

- Energy supply side: bottom-up, demand side: top-down
- Primary energy: natural gas, oil, coal, biomass, hydro&geothermal, wind, photovoltaics and nuclear energy
- Final energy demands: gaseous fuel, liquid fuel, solid fuel and electricity
- Interregional transportation of natural gas, crude oil, syn.oil, coal, methanol, hydrogen and CO_2
- CO_2 storage options: EOR operations, depleted gas well injection, aquifer injection and ocean injection
- Existing facility vintages of energy conversion are explicitly modeled.

Outline of the Climate Change Model

- Simple climate change model was constructed based on MAGICC (Model for the Assessment of Greenhouse gas Induced Climate Change).
  - Carbon circulation (both oceanic and terrestrial), atmospheric concentrations of other GHGs, their radiative forcings, temperature rises of 4 representative points (northern and southern hemispheres, ocean and land), sea level changes of northern and southern hemispheres (energy balance of upwelling stream among one dimensional 40 layers) etc. are calculated.
  - Cooling effect of SOx aerosol is taken into account.
- Temperature rises of 46x72 mesh points are calculated using the results of the above simple climate model and 11 layer model of UIUC (University of Illinois at Urban-Champaign)

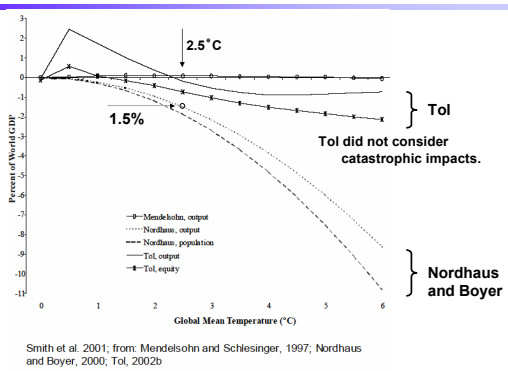
Outline of Warming Damage Model

- **Warming damage is assumed to be proportional to the square of temperature rise, which is adopted by S. Fankhauser, W.D. Nordhaus and others.**

$$DF_{n,t} = \eta \times GDP_{n,t} \times \left(\frac{\delta T_{n,t}}{\Delta T^0} \right)^2$$

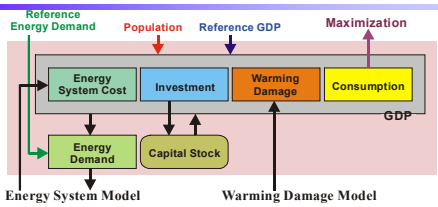
$\delta T_{n,t}$: temperature rise from pre-industrial level in ***n-th*** region, ***t-th*** time point, ΔT^0: global mean temperature rise for CO_2 doubling (=2.5°C), $GDP_{n,t}$: Reference GDP in ***n-th*** region, ***t-th*** time point, η: global warming damage coefficient

Estimated aggregate global damages relative to GDP



Smith et al. 2001; from: Mendelsohn and Schlesinger, 1997; Nordhaus and Boyer, 2000; Tol, 2002b

Outline of the Macroeconomic Model



- **The production function of a nested CES type**

$$Y = \left\{ a\left(K^{\alpha} L^{1-\alpha}\right)^{\rho} + \left(\sum_{i=1}^{4} b_i ED_i^{\mu} \right)^{\frac{\rho}{\mu}} \right\}^{\frac{1}{\rho}} \qquad \frac{dK}{dt} = IV - \zeta \times K$$

$$Y = EC + CS + IV + DF \qquad \sigma = 1/(1-\rho)$$

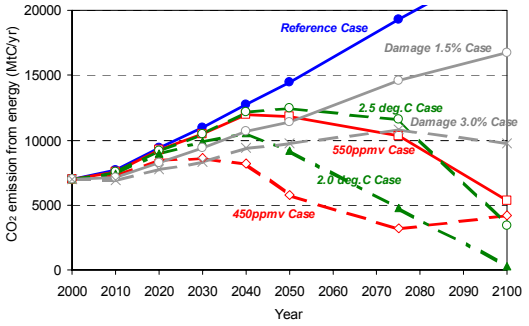
Y: GDP, K: capital stock, L: population, ED_i: ***i -th*** energy demand (***i*** =1:Gaseous fuel, 2:Liquid, 3:Solid, 4: Electricity), IV: capital investment, ζ: depreciation rate (=0.05), CS: consumption, EC: energy system cost, DF: warming damage, σ: elasticity of substitution

Analysis results using DNE21

Studied cases

- CO2 concentration stabilization
  550 ppmv and 450 ppmv
- Mean Temperature rise constraint
  2.0 ºC and 2.5 ºC from the pre-industrial level
- Cost- Benefit optimization
  Warming damage is 1.5% and 3% of GDP
  for 2.5 ºC rise (Two sensitivity cases)

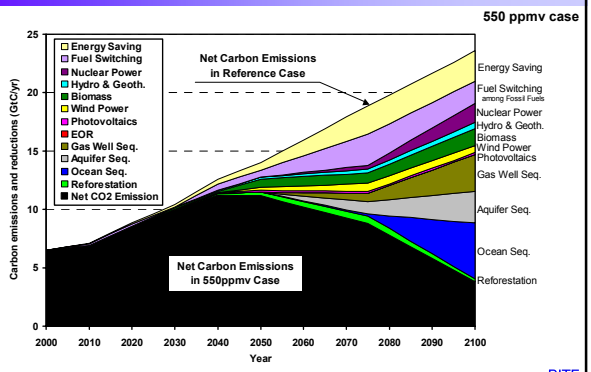
Optimized Global CO2 Emission Paths



Notes
Climate sensitivity : 2.5 ºC
Discount rate: 5% per year

Earlier reductions in damage cases

Technological Options for CO2 Emission Reduction



Implications from the Analysis

- Portfolio of technological options are necessary and not a single option is sufficient for GWM as widely acknowledged.
- Ultimate objectives of emission reductions is to alleviate warming damages, and then earlier emission reductions are required than when temperature rise or CO2 concentration is to be stabilized.

Due to the current limited knowledge especially about the warming impacts

- There exist limitations of IAM approach whose objective function is the global total cost.
- More attention should be given to the nature of warming damages.

What UNFCCC says about the Convention objective and the principles of objective-achieving actions.

UNFCCC

Article 2 Objective

"The ultimate objective of this Convention…is to *achieve…stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference* with the climate system. Such a level should be achieved within a time frame sufficient to allow *ecosystems to adapt naturally* to climate change, to *ensure that food production is not threatened* and to *enable economic development to proceed in a sustainable manner*."

UNFCCC

Article 3 Principles

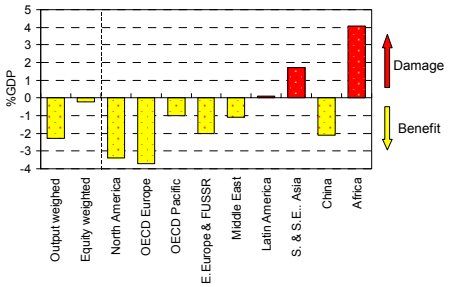
1. **The parties should protect the climate systems for the benefit of present and future generations of humankind, ---**
2. ***The specific needs and special circumstances of developing country parties especially those that are particularly vulnerable*** **to the adverse effects of climate change ---** ***should be given full consideration*****.**
3. ***The parties should take precautionary measures*** **---** ***Where there are threats of serious or irreversible damage, lack of full scientific certainty should not be used as a reason for postponing such measures*** **---**

Limitations of IAM approach and a New Methodology of Comprehensive Assessment

Limitations of IAM Approach

- Summing-up of regional damages to the world total for integrated assessment is ***not in accordance with "full consideration to vulnerable regions"***
- ***"Serious or irreversible damage" is not appropriately treated in terms of "precaution"***
- Monetary evaluation of all the kinds of damages is not necessarily appropriate; ***catastrophic events, biodiversity etc. are almost beyond monetary evaluation.***

Regional Difference of Damage



Damages for mean temperature rise of 1 ºC

Source: R.S.J. Tol, *Env. and Resource Economics*, 2002; Tol et al., *Global Env. Change*, 2004

New Methodology of Comprehensive Assessment

- **Warming damages to be given more attention**
  - ✓ **Regional differences to be given full consideration**
  - ✓ **Damages to be quantitatively evaluated but not necessarily in money**
  - ✓ **Catastrophic events to be prevented by precautionary principle**

  (Departure from the standard IAM approach)
- **Evaluation of GWM measures**
  - ✓ **Evaluation to be made for possibly damage-tolerable emission paths**
- **Comprehensive assessment of the both**

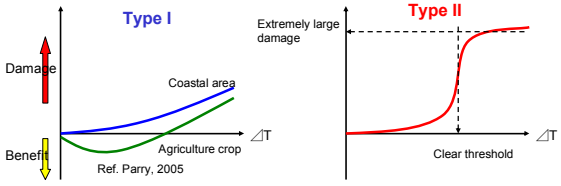
Two Types of Impacts

Impacts are likely to be classified into two groups.

Ref. Schneider, Exeter, 2005 etc.

Type I : Continuous events (agriculture crop etc.)

Type II : Catastrophic, irreversible or discontinuous events e.g. ocean thermohaline circulation (THC) collapse, disintegration of west antarctic ice sheet (WAIS)



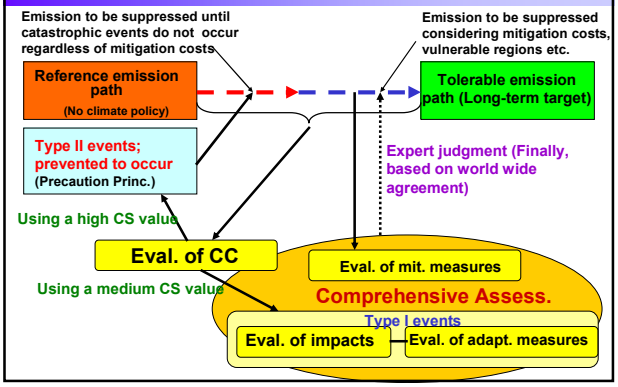
Differentiated Treatment of Two Types of Impacts in the New Methodology

- Catastrophic events (Type2 impacts) should be prevented by the precautionary principle; preventive measures to be taken independent of costs and with a high probability
- Continuous events (Type 1 impacts) should be quantitatively evaluated but not necessarily in money and their mitigation level is determined considering both damages and mitigation costs.
- A medium value* of climate sensitivity is used for evaluation of Type 1 impacts, and a high value** of CS for Type 2 impacts.

•*, **; tentatively 2.5 degree and 4.5 degree, respectively

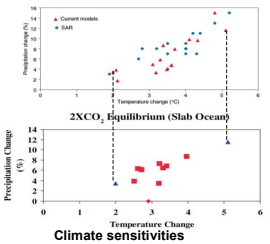
CS: Climate sensitivity

Assessment Procedure in the New Methodology



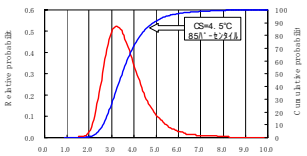
Uncertainty concerning Climate Science
CS Values for This Study（Tentative）

Improvements of climate models are continued since TAR, but the uncertainty of climate sensitivity is still large.



Climate sensitivities

Top： CSs in SAR(blue) and TAR (red)
Bottom：Blue triangle; Min. and Max in TAR, Red square; CSs submitted to WS2004 in Paris



Probability distribution (red) and Cumulative distribution (blue) Murphy et al. (2004)

4.5 **°C** for catastrophic events and 2.5 **°C** for continuous events are used tentatively

Implementation of the Comprehensive Assessment (underway)

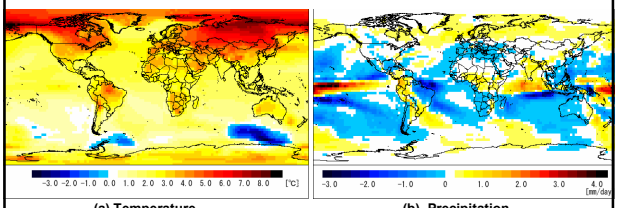
- Setting-up of reference emission path and suppressed emission paths
- Calculation of CC for the emission paths
- Evaluation of impacts for the emission paths; catastrophic events and continuous events
- Evaluation of GWM measures, costs etc. for the suppressed emission paths

Setting-up of Reference Emission Paths and Suppressed Emission Paths

- Reference emission paths are generated based on SRES and extended to 2200, using DNE21 model. (B2, A1FI and A1B)
- Suppressed emission paths for CO2 concentration stabilization of various levels are generated, which are harmonized with WRE paths/ IPCC WG1 paths for comparison purpose.

Calculation of CC for Suppressed CO2 Emission Paths

Simplified CC model and calculation results of AOGCM are linked to estimate world distribution of CC



(a) Temperature (b) Precipitation

Changes in yearly averaged temperature and precipitation in 2150 relative to those in 1990 (AOGCM：ECHAM4、CS：2.5 °C 、S550 emission path [Non-CO2 GHG emission of SRES B2 is added on.])

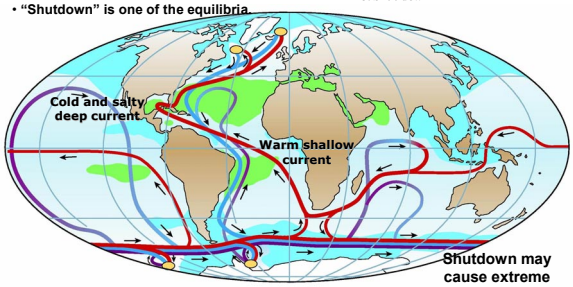
AOGCM: Atmosphere ocean general circulation model
S550 is the emission path generated for the 550 ppm stabilization by IPCC WG1.

Evaluation of Catastrophic Impacts (1-1)

Ocean Thermohaline Circulation (THC)

- There exist multiple stable equilibria.
- Transition between equilibria occurs in a short time of a few years to a few decades.
- "Shutdown" is one of the equilibria.

Three Equilibria
1. Sinking; both north and south of GIS
2. Sinking; north of GIS alone
3. Shut-down



Shutdown may cause extreme impacts.

From: Rahmstorf (Nature, 2002)

Evaluation of Catastrophic Impacts (1-2)

Ocean Thermohaline Circulation (THC)

Threshold level of THC shutdown

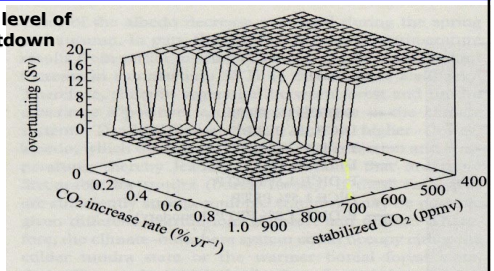
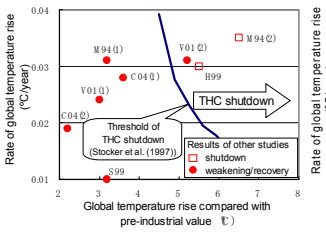


Figure 2. Equilibrium results of the SCD model under different forcing scenarios, from Schneider & Thompson (2000). THC overturning in sverdrups (1 Sv = 10^6 m^3 s^{-1}) is shown on the vertical axis as a function of the rate of CO_2 increase in the atmosphere and the stabilization concentration. Higher stabilization levels and more rapid rates of CO_2 increase make a THC collapse more probable.

Evaluation of Catastrophic Impacts (1-3)

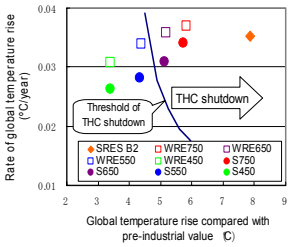
Tolerable CO2 Emission Path to Prevent THC Shutdown

Whether or not THC shutdown takes place



Comparison between THC shut-down threshold and results calculated by AOGCM (● : maintaining, □ : shut down)

CO2 Concentration must be below about 550ppm to prevent THC shut-down!



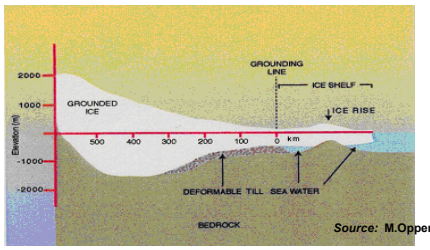
Judgment on whether THC shuts down (CS=4.5℃)

Evaluation of Catastrophic Events (2)

Disintegration of West Antarctic Ice Sheet

Judgment on whether WAIS disintegrates

- Disintegration of WAIS may cause sea level rise of 4-6m
- Some scientists reports that the disintegration may take place when the local temperature rise exceeds 10℃ (IPCC TAR) , but its confidence level does not seem high enough for quantitative evaluation



Source: M.Oppenheimer, *Nature*, 1998

Evaluation of Continuous Impacts

Agricultural crop

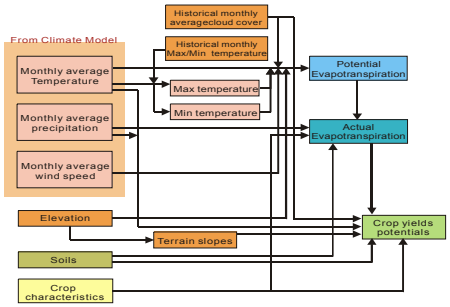
Human health etc.

Evaluation Model of Crop Yield Potential

- Reference emission paths are generated based on SRES and extended to 2200, using DNE21 model. (B2, A1FI and A1B)
- Suppressed emission paths for CO2 concentration stabilization of various levels are generated, which are harmonized with WRE paths/ IPCC WG1 paths for comparison purpose.

Estimation of Crop Yield Potential

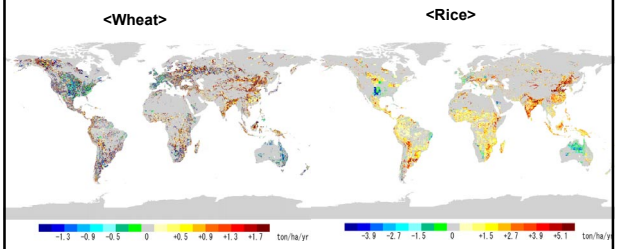
An estimation model has been constructed based on AEZ model and taking adaptation into account



Estimation Process for Crop Yield Potential

Note: The potential evapotranspiration is calculated by Penman-Monteith equation.

Evaluation of Continuous Impacts (1-1)
Change in Agricultural Crop Yield Potential



Production potential change of wheat and rice in 2150 (S550, planting time adaptation is considered)

Decrease is observed widely for wheat but only in limited area for rice.

Large regional difference

Evaluation of Continuous Impacts (1-2)
Impacts on Agricultural Crop Yield

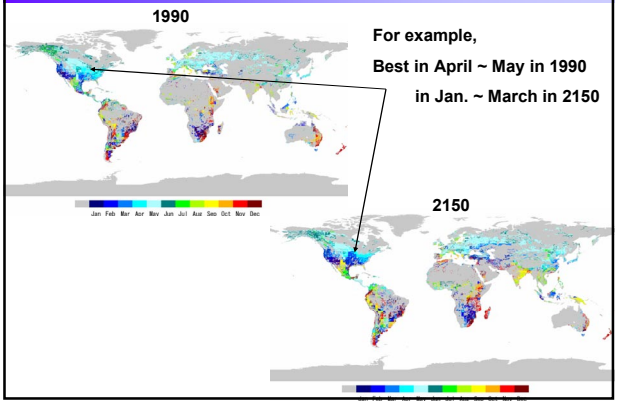
Yield potential change (S550, with and without adaptation)

	Production in 1990 (FAO)	Estimated potential in 1990	Projected potential in 2050 (ratio to 1990's)	Projected potential in 2150 (ratio to 1990's)
<Wheat>	560Mt/yr	6,770Mt/yr		
Without Adapt.			-13% (-58%)	-14% (-59%)
With Adapt.			+11% (-38%)	+3% (-43%)
<Rice>	520Mt/yr	9,580Mt/yr		
Without Adapt.			+0% (-52%)	-9% (-56%)
With Adapt.			+31% (-27%)	+2% (-43%)

Per capita potential change in parenthesis

Potential without adaptation decreases even for S550, but it is projected to increase when adaptation and productivity improvement are considered

Adaptation of Wheat Planting Timing (S550)



For example,

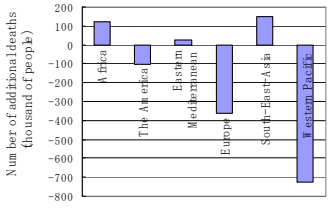
Best in April ~ May in 1990

in Jan. ~ March in 2150

Evaluation of Continuous Impacts (2)
Impacts on Human Health

<Heat stress>

Cardiovascular and respiratory diseases



Mortality increase due to heat stress in 2050 relative to Reference case (Nationwide estimates are aggregated into 6 regions. S550)

<Malaria>

Estimates are made for 10 regions for S550 emission path.

Mortality in 2050 increases only for sub-Saharan region as compared to Reference case; Mortality increase is 8.3 million people in 2050, which is 9% of Reference case mortality; no mortality increase for any region in 2150

Estimation based on R.S.J. Tol (2002)

Evaluation of Continuous Impacts (3)

Coastal area (loss of land due to SLR), biodiversity, forestry, fishery etc are under assessment process based on literatures; the followings are tentative:

<Coastal area>

Bangladesh ; 12% of land goes below sea level in 2150 for S550 path.

<Biodiversity>

15-37% of terrestrial species in a sampled region may be extinguished in 2050 for a medium warming scenario (C. Thomas et al.)

<Fishery>

A warming of the magnitude predicted is more likely than not to be beneficial to the fisheries of the North Atlantic (R. Arnason)

Acidification of sea water may solve some planktons having $CaCO_3$ shell and impact food chain of ocean ecosystem (J. Orr et al)

<Forestry>

Warming may be beneficial to growth of trees as the world total but regional difference is large

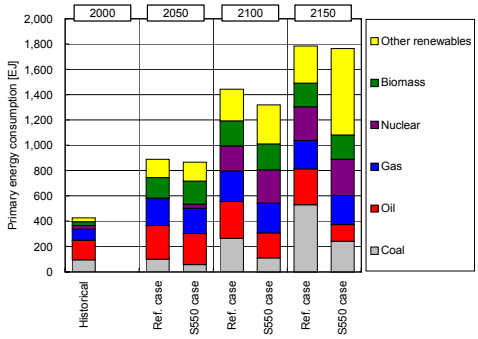
Risk of wild fire and disease carrier increase

Evaluation of GWM Measures, Costs etc

- **Analyses with DNE21 Model**
  Focus on Long-term energy systems changes
- **Analyses with DEARS* Model**
  Focus on industrial structure changes as well

(Dynamic Energy-economic Analysis model with multi-Regions and multi-Sectors; newly developed)

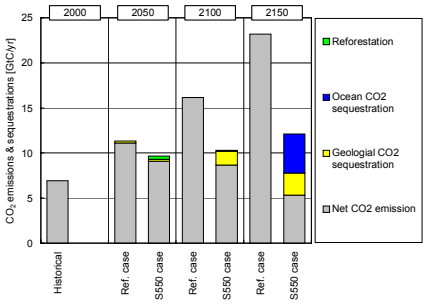
Evaluation of GWM Measures with DNE21
Long-term Energy Systems Changes (1)



Global primary energy structures for Ref. case and S550 case

Fossil fuel consumption decreases, and renewables and nuclear substitute for it in S550 case.

Evaluation of GWM Measures with DNE21
Long-term Energy Systems Changes (2)



Global CO2 emission and sequestration for Ref. case and S550 case

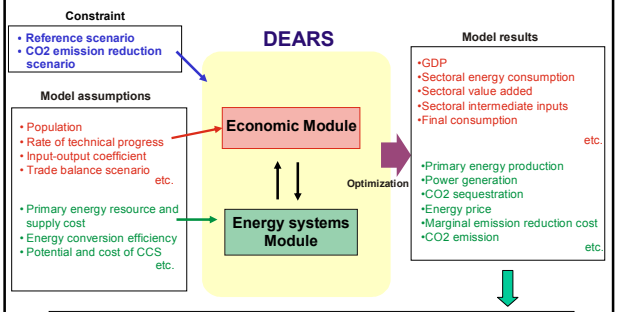
For S550, sequestration by reforestation first, and thereafter underground and ocean sequestration is cost-effective

Outline of DEARS Model

Dynamic Energy-economic Analysis model with multi-Regions and multi-Sectors

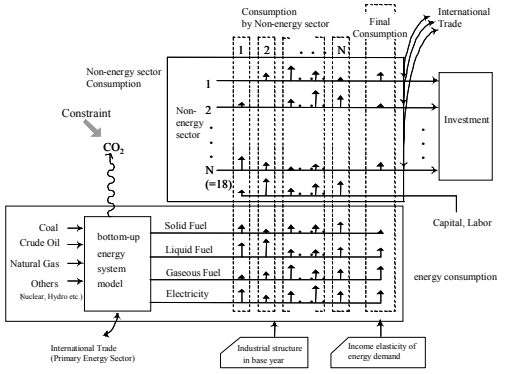
- Integration of a top-down economic module and a bottom-up energy systems module
- Economic module through GTAP(ver.5) database (input-output table)
- Energy systems module based on energy model DNE21
- 18 region division of the world
- 18 sector division of non-energy industry
- 7 kinds of primary energy and 4 kinds of secondary energy with the consideration of CCS (Carbon Capture and Storage)
- Model time span: Up to the middle of the 21st century
- Intertemporal nonlinear optimization model (maximization of discounted total consumption utilities)

Inputs and Outputs of DEARS Model



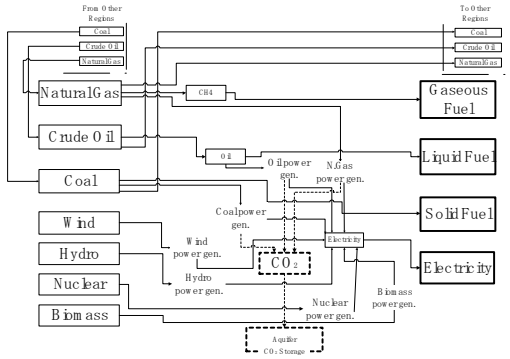
World and regional strategies for climate change mitigation up to the middle of the 21st century with consideration of changes in industrial structures and energy systems

Integration of Energy and Non-energy Sectors in DEARS



Structure of Energy Systems Module

-Energy Conversion Processes and CCS-



Model Structure of Economic Module

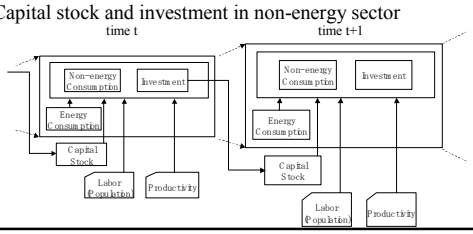
- Non-energy sectors: Leontief-type production function
- Macro-economy: Cobb-Douglas type production function
  (capital, labor, electricity, and non-electricity)
- Objective function:

$$\text{Maximize} \quad \sum_t d_t \cdot \sum_r L_{r,t} \cdot \sum_i \theta_{i,r} \cdot \log \frac{C_{i,r,t}}{L_{r,t}}$$

i, j: sector
t : time
r : region

C :consumption
θ :sectoral consumption weight (exogenous), d:discount factor (exogenous) ,L:population(exogenous)

- Capital stock and investment in non-energy sector



18 non-energy industry and 11 types of energy

- 18 non-energy industrial sectors

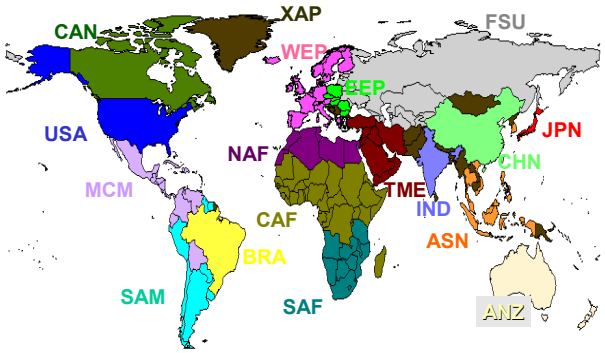
I_S	Iron and steel	LUM	Wood, and wood products
CRP	Chemical industry	CNS	Construction
NFM	Non-ferrous metals	TWL	Textiles, wearing, apparel and leather
NMM	Non- metallic materials	OMF	Other manufacturings
TRN	Transport equipments	AGR	Agricultural products
OME	Other machinery	T_T	Transportation
OMN	Minings	ATP	Aviation
FPR	Food Products	BSR	Business services
PPP	Paper, pulp and printings	SSR	Social services

- 7 types of primary energy and 4 types of secondary energy

Coal	Primary Energy
Crude Oil	
Natural Gas	
Biomass	
Wind	
Hydro	
Nuclear	

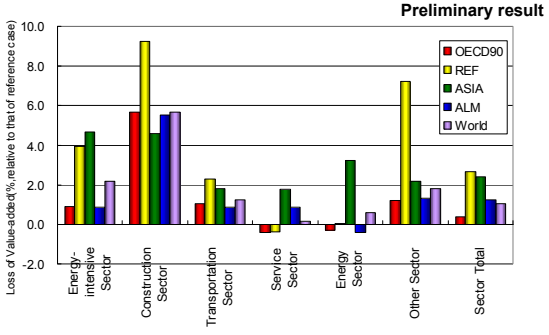
Solid Fuel	Secondary Energy
Liquid Fuel	
Gaseous Fuel	
Electricity	

Divided 18 regions



Loss of VA (value-added) by Sector

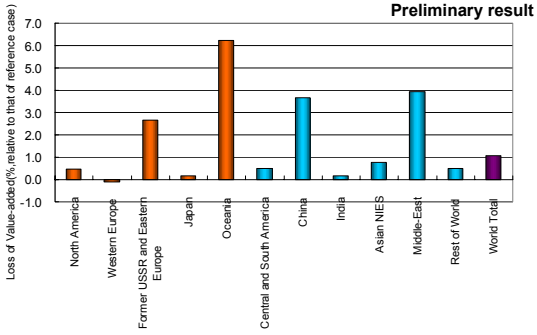
Preliminary result



VA loss relative to base year's VA in 2027 for S550 case (Base year:1997)

Loss of GDP by Region

Preliminary result



GDP loss relative to Reference case's GDP for S550 case

Example of a quick-look table of the results

- For emission paths which ensure the prevention of catastrophic events (Type II events)

Quantitatively evaluated impacts of continuous events (Type I events), including regional differences

Costs of mitigation, detailed regional measures etc. are listed.

Emission Path	Type II prevention		Type I events (W/Without adaptation)				Costs & measures of mitigation
			CC	Crop yields	Human health	・・・	
Ref. (SRES A1)	No		–	–	–	–	
Ref. (SRES B2)	No		–	–	–	–	
S550	Yes	2050	CC by region	Yield potential change by crop and by region	Additinonnal deaths by disease and by region etc.		VA loss by sector and by region etc.
		2100					GDP loss by region etc.
		2150					GWP loss etc.
"S500"	Yes	・・・					
・・・	Yes	・・・					

Concluding Remarks (1/3)

- Assessments with IAM; when costs of mitigation and damages are minimized and damages are assumed proportional to square of T-rise, earlier emission is required than when concentration or temperature rise is stabilized.
- Past IAM analyses have limitations;
  - Regional differences smothered in world total
    Full consideration not given to vulnerable regions
  - Type 2 impacts
    Required "Precautionary measures" are not taken into account
  - Some kinds of impacts are hard to evaluate in money
    Impacts on ecosystem, species extinction etc.

Concluding Remarks (2/3)

- A new way of comprehensive assessment is proposed
  - More attention to damages; prevention of catastrophic events, regional differences shown explicitly and quantitative but not necessarily monetary evaluation
  - Evaluation of mitigation measures for possibly damage-tolerable emission paths
  - The both of the above are comprehensively evaluated.
- The long-term target of GWM
  - About 650ppmv CO2 eq. (tentative) is necessary for Type 2 events prevention
  - Quick look tables of the results and a briefing book will be prepared for expert judgment on the target

Concluding Remarks (3/3)

- As parts of the comprehensive assessment,
  - An estimation model of crop yield potential with adaptation taken into account has been developed; adaptation of planting timing is optimized
  - A dynamic energy- economic analysis model with multi-regions and multi-sectors have been developed.
- The Project will be completed by the end of FY2006