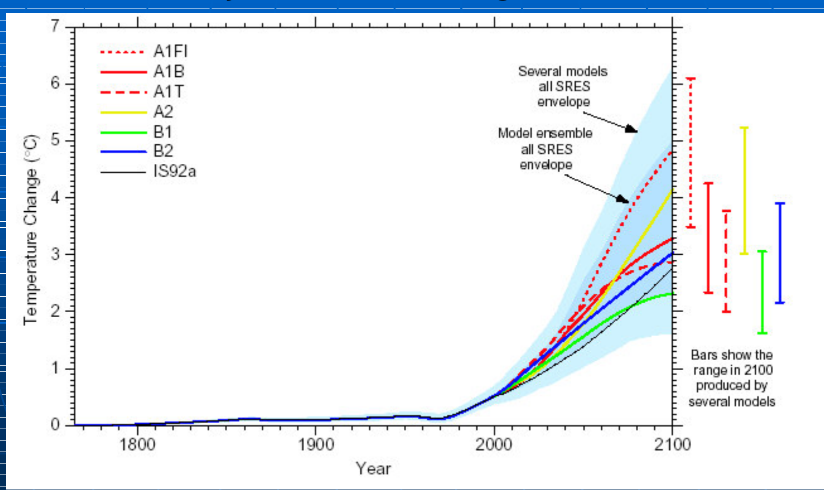
Outline of the Integrated Assessment of Global Warming and its Mitigation Technologies in the Changing World Economy and Industry Project and some extensions of MARIA

RITE Systems Analysis Group, Project Leader
Tokyo University of Science

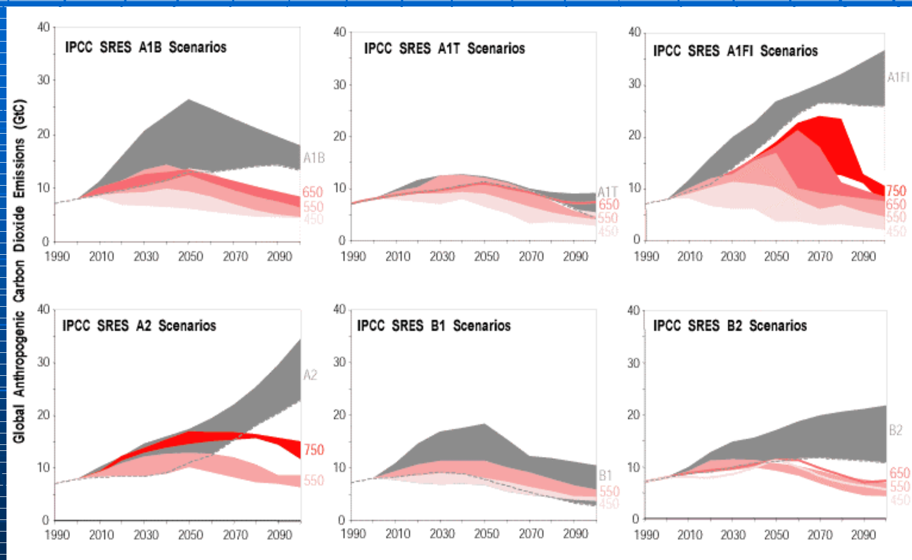
Shunsuke Mori

Introduction • – Global environmental issue as a subject for the next generation



Global mean temperature projections for the six illustrative SRES scenarios (IPCC WG-1, 2001)

Global environmental issue as a subject for our society



Carbon emission trajectories with and without control policies in SRES six scenarios (IPCC-SRES, 2000)

Global environmental issue - subjects for our society

- IPCC-TAR (2001) summarized the recent scientific findings on global warming issues.
- So many impacts may appear due to the global warming in spite of various uncertainties.
- Environmental policies should be evaluated incorporating energy, economy, societal and technological issues.
- IPCC-TAR stressed the importance of DES (Development, Equity and Sustainability) as the first priority issue.

Integrated Assessment Models as a platform of the policy and technology assessments

- Integrated assessment models (IAMs) have been developed since 1990s as a powerful tool for this subject. *However,*
- Economic models and technology assessments deal with near future (until 2020) while existing IAMs mainly talk about near 2100.
- Economic models and technology assessments mainly analyze country level while existing IAMs mainly aggregate the world into 10-15 regions.
- Globalization, civilization, penetration of IT, industrial structure changes etc. are not well discussed in the global environmental context.

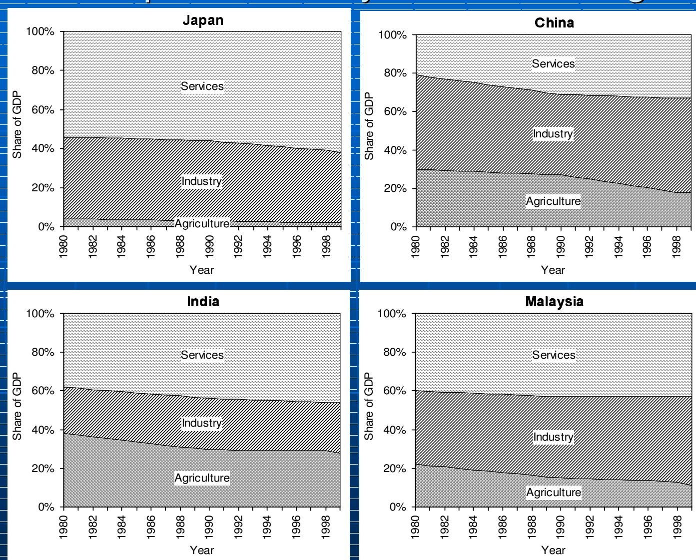
Example-1: interdependence of world economy

Table • • Annual grow rates of international trades

	1990 • 1993	1994 • 1995
World	4.4	9.2
OECD intra-regional trade	2.2	7.8
OECD-Non OECD trade	7.5	10.7
NonOECD intra-regional trade	8.8	15.2

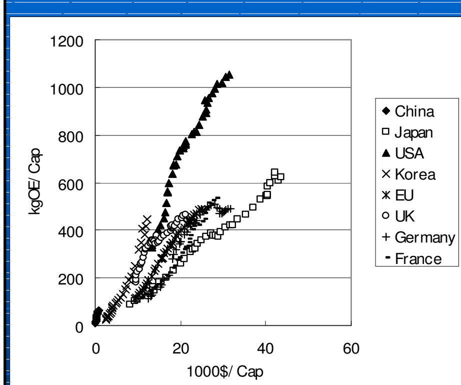
Source: OECD, "World Economy in 2020", 1999

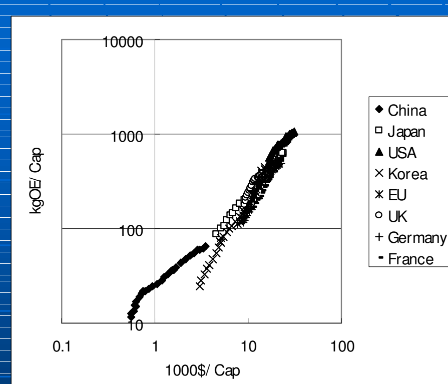
Example-2: industry structure changes



Industry structure change profiles for 1980-1999
Source•World Bank, World Development Indicators 2000; 2001•

Example-3: long-term trends in historical demands

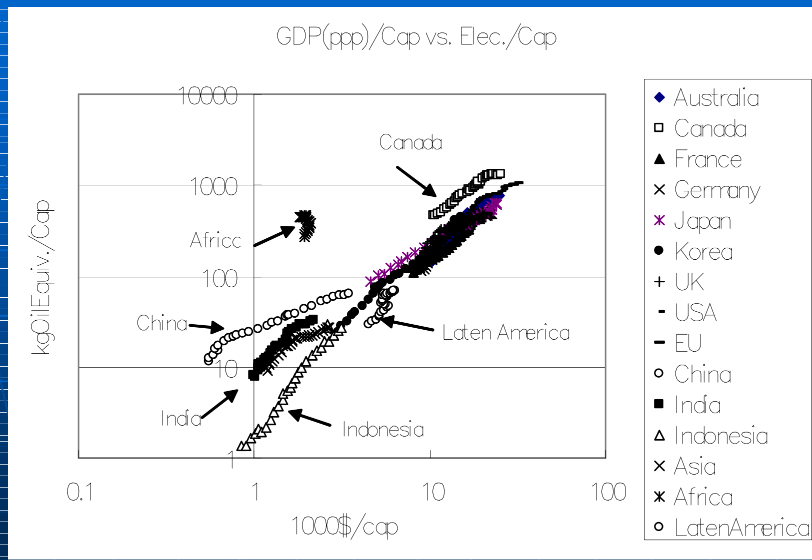




(a) GDP-mex in 1995 prices•••• (b) GDP-PPP in 1995prices

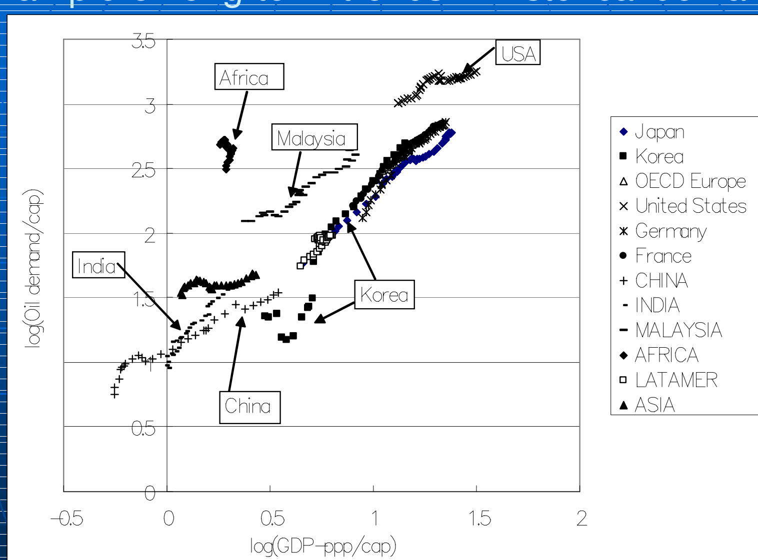
We can observe the stable long-term historical trends in the right figure on the relationship between per capita electricity demand in public sector and per capita GDP-PPP.

Example-4: long-term trends in historical demands



Per capita electric power consumption vs. per capita GDP-PPP

Example-5: long-term trends in historical demands



Per capita transportation oil demands and Per capita GDP-PPP

Project Phoenix
- Paths toward Harmony Of Environment, Natural resources and Industry complex –

- **Developed by the RITE - Research Institute of Innovative Technology for the Earth**
- **Supported by the Ministry of Economy, Trade and Industry as a part of an "International Research Promotion Funds for the Global Environment"**
- **A project for 2002-2006 (five years)**

Targets of the Project Phoenix

Development of an IAM dealing with

- Regional conditions
- Structural changes in economic activities
- Focusing on the middle term around 2050
- Long-term trends in historical demands

Three Integration directions

- Energy technologies, economic activities, environmental impacts..
  Integration of fields
- Scientific knowledge, human behavior, technological developments..
  Integration of uncertainties
- Quantitative, qualitative, descriptive..
  Integration of information properties

Structure of Project Phoenix – three WGs

Multi region and sector model GTAP

+ Easy to connect with GAMS
- Dynamics
- Aggregated energy technologies and sources

(Model development WG)

Energy demand, economic activities, structural changes

+ Data availability (trade and economic statistics)
- Societal structural change

(Warming factors WG)

Assessments of global warming

+ Availability on food, water, climate change studies
- Uncertainties of global warming damages

(Warming impacts WG)

A: Model development WG aims at the development of the basic assessment tools

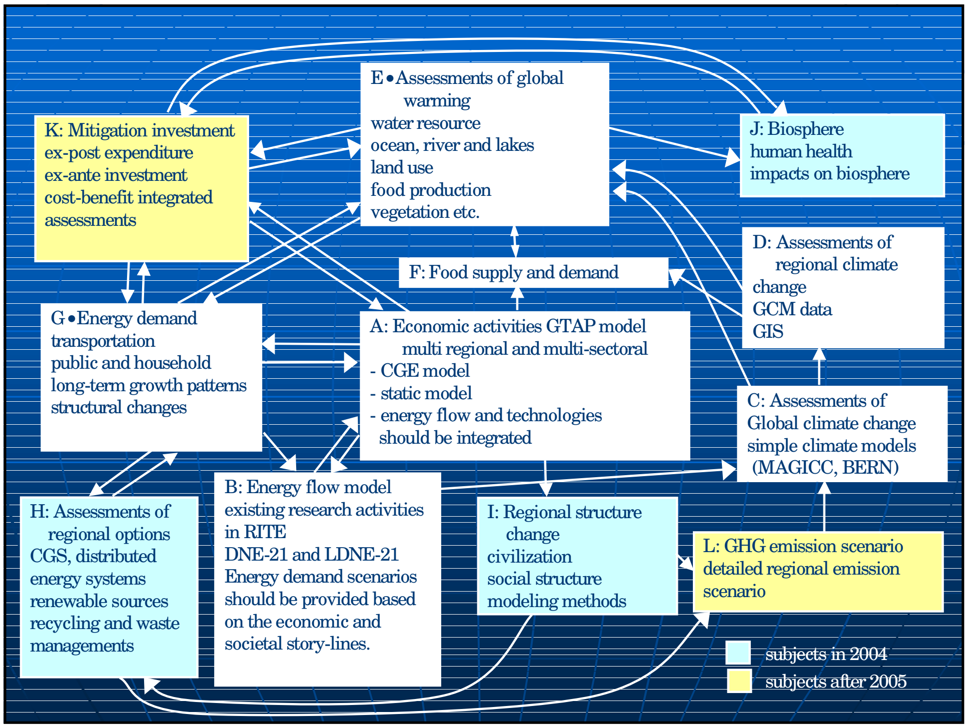
- **Integration of static GTAP model and energy technology models (DNE-21, LDNE-21)**
- **Dynamic extension of the model**
- **Assessments of structural changes in the model**
- **Expansion of regions and sectors**

B: Global warming factors WG aims at the development of scenarios in terms of the global warming factors.

- Collecting and summarizing the statistics and information
- Extracting the key trends in the statistics
- Providing the energy, food and other demand scenarios
- Assessing the structural changes based on the narrative and qualitative events applying technological forecasting methods
- Assessing the regional development scenarios toward the assessments of CGS and other regional options. (2nd stage)

C: Global warming impacts WG aims at the development of the scenarios on the warming impacts and mitigation options

- Collecting and summarizing the statistics and information
- Extracting the key trends in the statistics using GIS
- Assessing the relationships between climate change and the impacts focusing on the water resources, food production, vegetation, land use changes, health effects etc.
- Assessments on ex-ante investments and ex-post expenditure toward the integrated assessments (2nd stage)



Procedure of Structure Analysis

(1) Global warming impacts are initially assumed according to the IPCC-TAR-WG2 findings.

(2) Extract the factors which will impact and will be impacted by the global warming based on the questionnaire as well as the factors which will accelerate and will mitigate the warming.

(3) Analyze the causality and impact structure of the factors and classify into hierarchical categories.

(4) Generate the "most likely" scenario and alternatives applying X-I method.

(5) Impose the parameter settings, constraints and other possible conditions to the IAM according to the scenario.

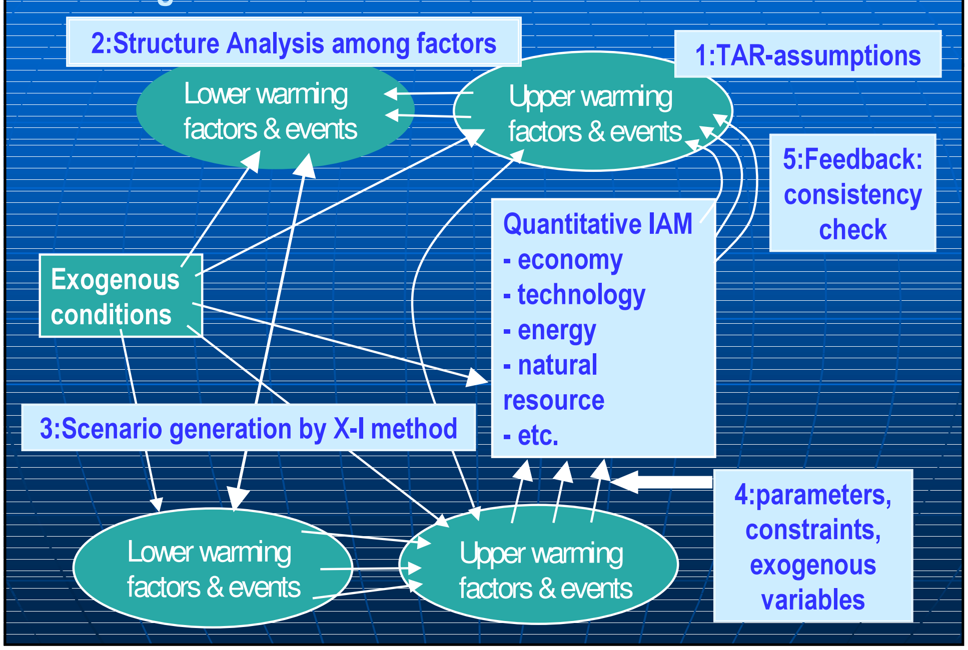
(6) Check the over-all consistencies.

Questionnaire to extract the experts' judgments on the interactions among global warming factors

A: Global warming impact events	Level of uncertainty	Major regions	Major factors impacted by the event	Factors which will accelerate the impact	Options and factors which will mitigate the undesirable impact
(ex.) shortage of urban water supply	High	China Africa	-Sanitation (H) -Health (M) - manage-ment of parks (M)	-Rapid civilization (H) -Concentration of population (H) -Deterioration of water resources (H)	-usage of rainwater (M) -Advanced water recycle system (M)

(*) The reference climate change and impacts follow the IPCC-TAR-WG2.

Integration : Scenario Generation and Simulations



Scenario Generation using X-I method -1

Originally developed by Gordon (1965) to see the complicated interactions among the events .

(1) Estimating the probability of occurrence of each technology

(2) Evaluate the degrees of impact among events

(3) Revise occurrence probabilities using Monte Carlo simulation.

Dalky pointed out the mathematical consistency in 1972.

Duperrin and Godet (Duperrin, 1975) proposed a new method to guarantee the mathematical consistency.

Kaya et. al. (Kaya, 1979) expanded their method•

(1)using causality probabilities instead of conditional probabilities based on the Markovian probability model.

(2)sequential linear programming method to assess the range of high dimensional state probabilities.

Dynamic expansion has been developed (Mori, 1984).

Scenario Generation using X-I method -2

1. Determine the set of events to be considered during the forecasting period.

2. Define the exogenous conditions affecting the event occurrences one-sidedly.

3. Estimate the occurrence probability of event i (i=1,2…n) at the end of the forecasting period P(i).

4. Estimate the "impact probability" P(i •j) : the occurrence probability of event j given the condition that the event i occurs solely in the beginning of the period.

5. Calculate the two-dimensional probability applying Markovian transition model.

6. Construct the mathematically consistent probabilities modifying estimated two dimensional probability data set by

$$\min.J = \sum_i w_i \{P(i) - P^*(i)\}^2 + \sum_{j \neq i} w_{ij} \{P(i,j) - P^*(i,j)\}^2$$

where the consistent probabilities P* (i), P* (i,j) are the linear combinations of n-dimensional state probabilities { $\bullet_k$} .

Scenario Generation using X-I method -3

7. Calculate the ranges of $\{ \bullet_k \}$ using linear programming.

$$\begin{matrix}\min.\\ \max.\end{matrix}\ \pi_k \quad \text{subject to } P^*(i)=\sum_k d_i^k \pi_k\ ,\quad P^*(i,j)=\sum_k d_i^k d_j^k \pi_k\ ,\quad \sum_k \pi_k = 1\ ,\quad \pi_k \geq 0$$

π_k :n-dimensional probability $P(d_1^k, d_2^k, \cdots d_n^k)$ $(k = 1,2,\cdots 2^n)$.

d_i^k =1 if even i occurs in the state k else d_i^k =0.

ex. Nuclear power technology forecasting for 1990-2010 (Mori and Kaya, 1984)

(1)FBR: some FBR(Fast Breeding Reactor)s are already developed.

(2)ATR: some ATR(Advanced Thermal Reactor)s are already developed.

(3)CAND: some CANDU-PHW reactors are developed.

(4)LWR-Pu: share of Plutonium recycling comes to 33% of total LWR fuel.

(5) Repro: some reprocessing systems for LWR-Pu or ATR are operating.

(6) Cent: some centrifugal separation plants are developed.

(7) Coal: the share of coal fired power generation comes to more than 20% of world electric power supply.

Example of X-I method - *continued*

	Scenario A		Scenario B
1990		(0000000) 0.688	
1995	(0000001) .22-.42	(0000000) A : .25-.45 B : .27-.51	(0000010) .18-.37
2000	(0000011) .42-1.0		(0001110) .12-.93
2005	(0000011) .32-.81		(1001110) .33-.82
2010	(1000111) .09-.17		(1001110) .09-.12

(1) FBR
(2) ATR
(3) CAND
(4) LWR-Pu
(5) Repro
(6) Cent
(7) Coal

upper:occurrence state lower: range of probability

Scenario A : Coal-nuclear scenario
Scenario B : Nuclear oriented scenario

Dynamic scenario sequences from 1990-2010

Preliminary results of MARIA with Learning Effects

- Learning effects and scale of economy are the important factors to assess the R&D strategies.

- The progress of algorithm and computation power have enabled the modelers to involve them in IAMs ; Messner (1995), Kram (2001), Miketa (2001), Barreto (2002), Manne (2002), Klaasen (2002), Gerlagha(2002)...

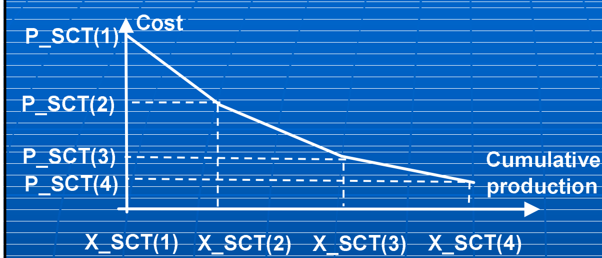
MARIA with LBD is developed to see the penetration process of new energy technologies:

- Renewables: solar power (PV) and windpower (WIND)

- Advanced fossil fuel based technologies: coal based integrated gas combined cycle (IGCC), solid oxide fuel cells (SOFC) and gas based combined cycle plant (GCC)

Current MARIA with LBD incorporates energy, economy and global warming subsystems. Food, land use change, nuclear fuel recycling, hydrogen and carbon sequestration options are not included.

Calculation procedure



Using binary variables $\{\delta_m\}(m=1..4)$ and positive variables $\{\lambda_m\}(m=1..4)$

$$X=\lambda_1 X\_SCT(1)+\lambda_2 X\_SCT(2)+\lambda_3 X\_SCT(3)+\lambda_4 X\_SCT(4) \quad (A.1)$$

$$P=\lambda_1 P\_SCT(1)+\lambda_2 P\_SCT(2)+\lambda_3 P\_SCT(3)+\lambda_4 P\_SCT(4) \quad (A.2)$$

$$\lambda_1 \quad -\delta_1 \le 0 \quad (A.3)$$

$$\lambda_2 \quad -\delta_1-\delta_2 \le 0 \quad (A.4)$$

$$\lambda_3 \quad -\delta_2-\delta_3 \le 0 \quad (A.5)$$

$$\lambda_4 \quad -\delta_3-\delta_4 \le 0 \quad (A.6)$$

$$\sum_k \delta_k=1 \quad (A.7)$$

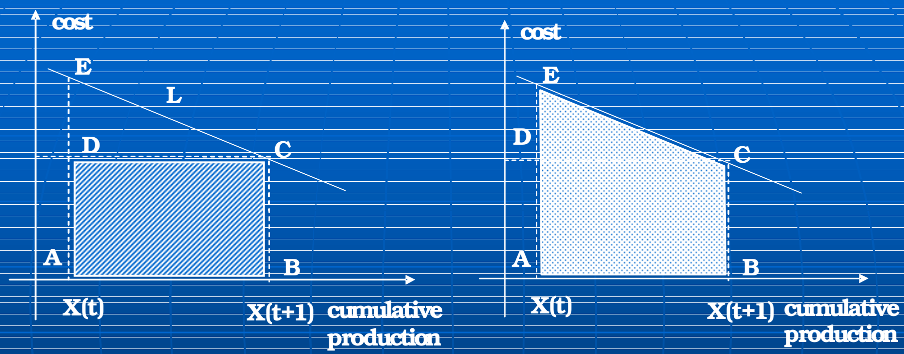
$$\sum_k \lambda_k=1 \quad (A.8)$$

Stage 1: Solve the model-0 without (A.1)-(A.8) using **NLP** fixing the costs P_0 to be the certain initial values.

Stage 2: Add the constraints (A.1), (A.2) and (A.8) and solve this model (model-1) using **NLP**. The cost curve (left Figure) does not hold.

Stage-3: Find the section k to which X belongs. Then •, • and new initial P are defined. Add the (A.3)-(A.7) and solve the full model-2 using **MINLP**

LBD and the Scale of Economy



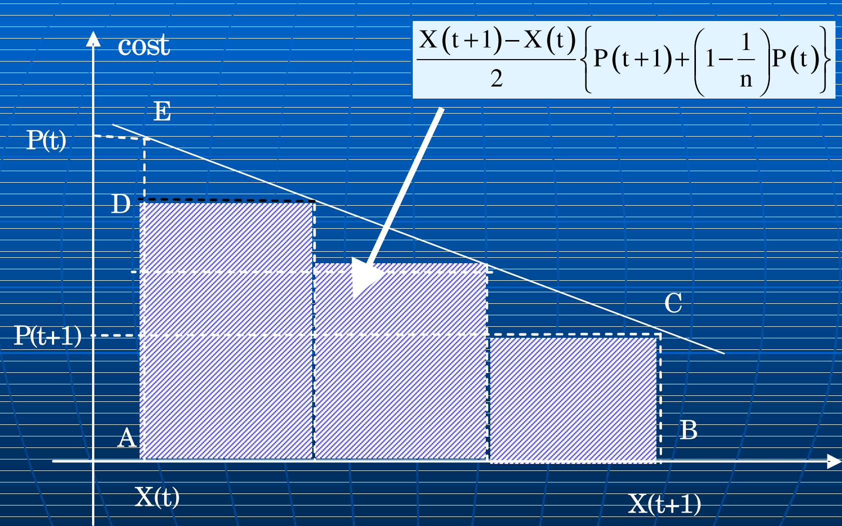
(a) Scale of Economy (b) LBD

If the decreasing cost curve **can be foreseen** by the firm, he decides the production in period t without experiencing the production of L. Total expenditure is ABCD. (Figure (a))

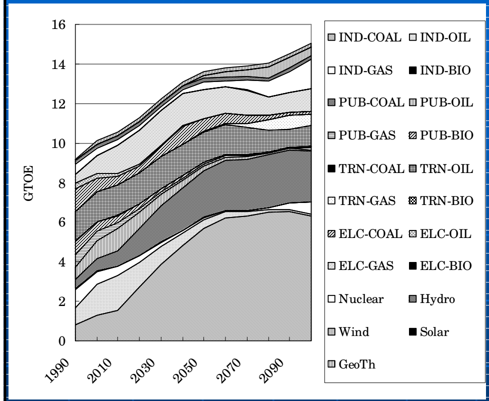
When the decreasing cost curve EC is achieved through the experience of production, total expenditure is represented by ABCE.

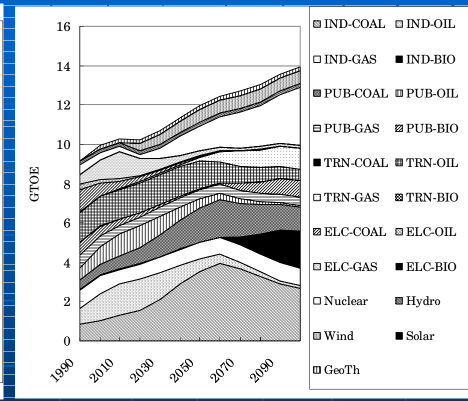
ABCD is not always a monotonous increasing function of X(t+1).

LBD and the Scale of Economy – practical case?



Simulation Results of MARIA with LBD -1



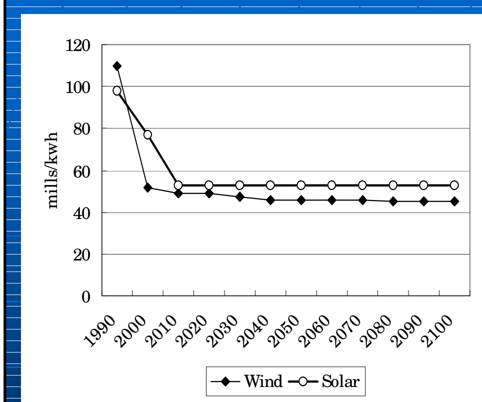


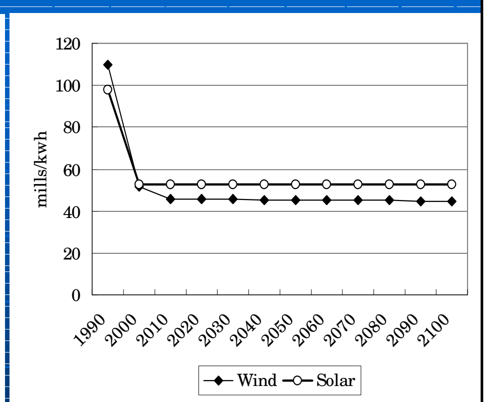
Primary energy supply profile of MARIA-LBD in BAU

Primary energy supply profile of MARIA-LBD in carbon control at 550ppmv case

Windpower, nuclear and biomass increase and are implemented earlier in carbon control case.

Simulation Results of MARIA with LBD -2



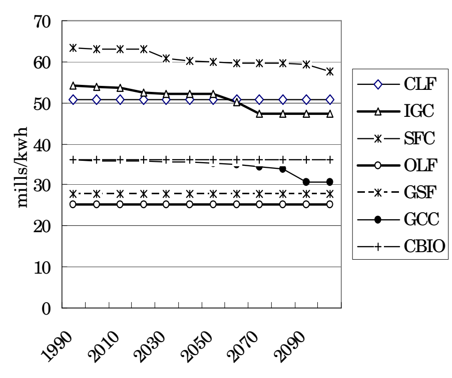


MARIA-LBD in BAU

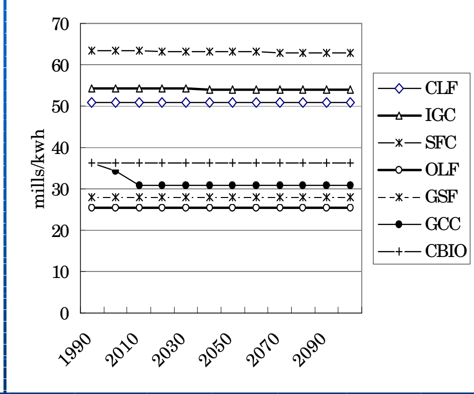
MARIA-LBD in carbon control at 550ppmv case

Endogenous cost change profiles of windpower and solar PV

Simulation Results of MARIA with LBD -3



MARIA-LBD in BAU



MARIA-LBD in carbon control at 550ppmv case

Endogenous cost changes of fuel based power generation plants in BAU and carbon control cases; costs of conventional plants i.e., coal fired plant (CLF), oil fired plant (OLF), gas fired plant (GSF) and biomass power plant (CBIO), are constant

Expected outcomes

- **The changes of the energy supply-demand systems, industry structure changes and the international industry allocation scenarios will provide the basic information to assess the policy measures.**
- **The outcomes of the project will give the helpful information on the energy technology development strategies.**
- **The most preferable burden sharing scenario on the carbon emission reduction can be generated.**
- **Industry policies on the R&D on the energy and environmental technologies, technology transfer, and other industry strategies can be assessed under the global warming mitigation policies.**