An Integrated Assessment of Global Warming Mitigation and Adaptation and the Development of Multi-regional and Multi-sector IAM

- Project Phoenix -

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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.

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)**

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

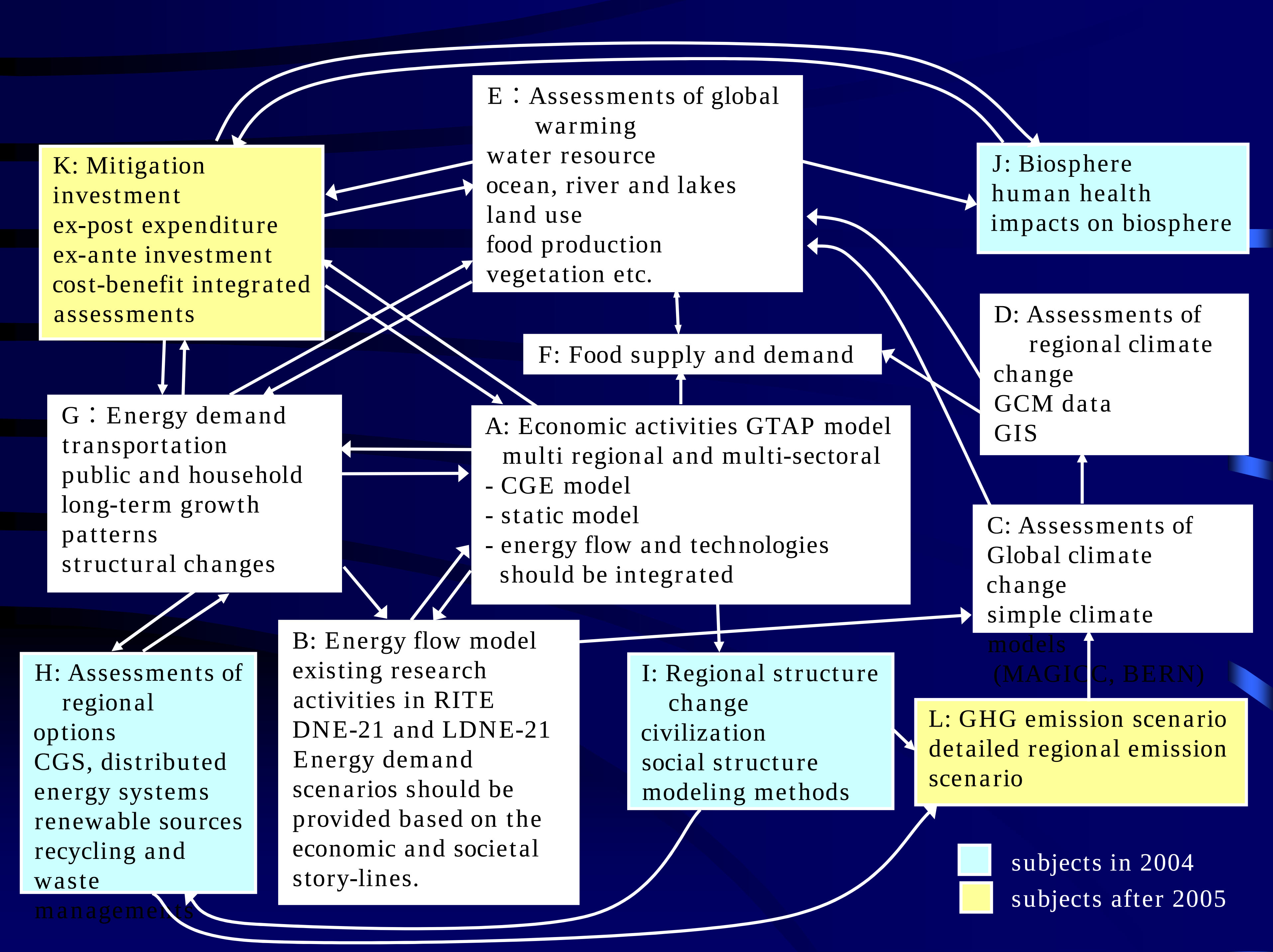
+ Data availability (trade and economic statistics)
- Societal structural change

(Warming factors WG)

Assessments of global warming

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

(Warming impacts WG)


E：Assessments of global warming
water resource
ocean, river and lakes
land use
food production
vegetation etc.
K: Mitigation
investment
ex-post expenditure
ex-ante investment
cost-benefit integrated assessments
J: Biosphere
human health
impacts on biosphere
D: Assessments of regional climate change
GCM data
GIS
F: Food supply and demand
G：Energy demand
transportation
public and household
long-term growth patterns
structural changes
A: Economic activities GTAP model
multi regional and multi-sectoral
- CGE model
- static model
- energy flow and technologies should be integrated
C: Assessments of Global climate change
simple climate models
(MAGICC, BERN)
H: Assessments of regional options
CGS, distributed energy systems
renewable sources
recycling and waste managements
B: Energy flow model
existing research activities in RITE
DNE-21 and LDNE-21
Energy demand scenarios should be provided based on the economic and societal story-lines.
I: Regional structure change
civilization
social structure
modeling methods
L: GHG emission scenario
detailed regional emission scenario
subjects in 2004
subjects after 2005

Tentative IAM structure and results

- GTAP (Purdue Univ.) incorporates more than 60 regions and sectors and is still being expanded.
- GTAP is designed to assess the international trade and production impacts of various policy options.
- GTAP-EG includes energy flow subsystems.
- GTAP provides comprehensive and consistent world economic data base.

In Phoenix Project,

- We aim at the assessments of the certain technologies such as energy conversion technologies, carbon capture options, biomass production and utilization, etc.
- Dynamic model simulation is also needed.
- We impose the bottoming up technology model into the GTAP model simplifying the frame, if necessary.

Conceptual Frame of the Model

			Intermediate Inputs				Final demand			
			Non-energy sectors		Energy sectors		trade	Investments	Consumption	Output
			1	2	Primary	Secondary	m	I	C	Q
Int. Inputs	Non-energy Sectors		X_{11}=	X_{12}=		0	m_1	I_1	C_1	Q_1
						0				
				0		X_P				
				X_{e2}= P_eE_2		0		0	P_eE_c	P_eE
Value Added		K	$P_k \cdot K_1$	$P_k \cdot K_2$	VA_pre	VA_E				
		L	$P_L \cdot L_1$	$P_L \cdot L_2$						Y
Output		Q	Q_1	Q_2	EC_pre= PpS	EC= PeE				Q

VA_Epre= Σ (capital and labor costs of primary energy extraction and production costs)+(others)

VA_E= Σ (capital and labor costs of energy conversion technologies)+(others)

V=f(K,L,E)-(secondary energy input costs)

(Total secondary energy supply)= Σ (Conv. Eff.)＊(primary energy inputs)

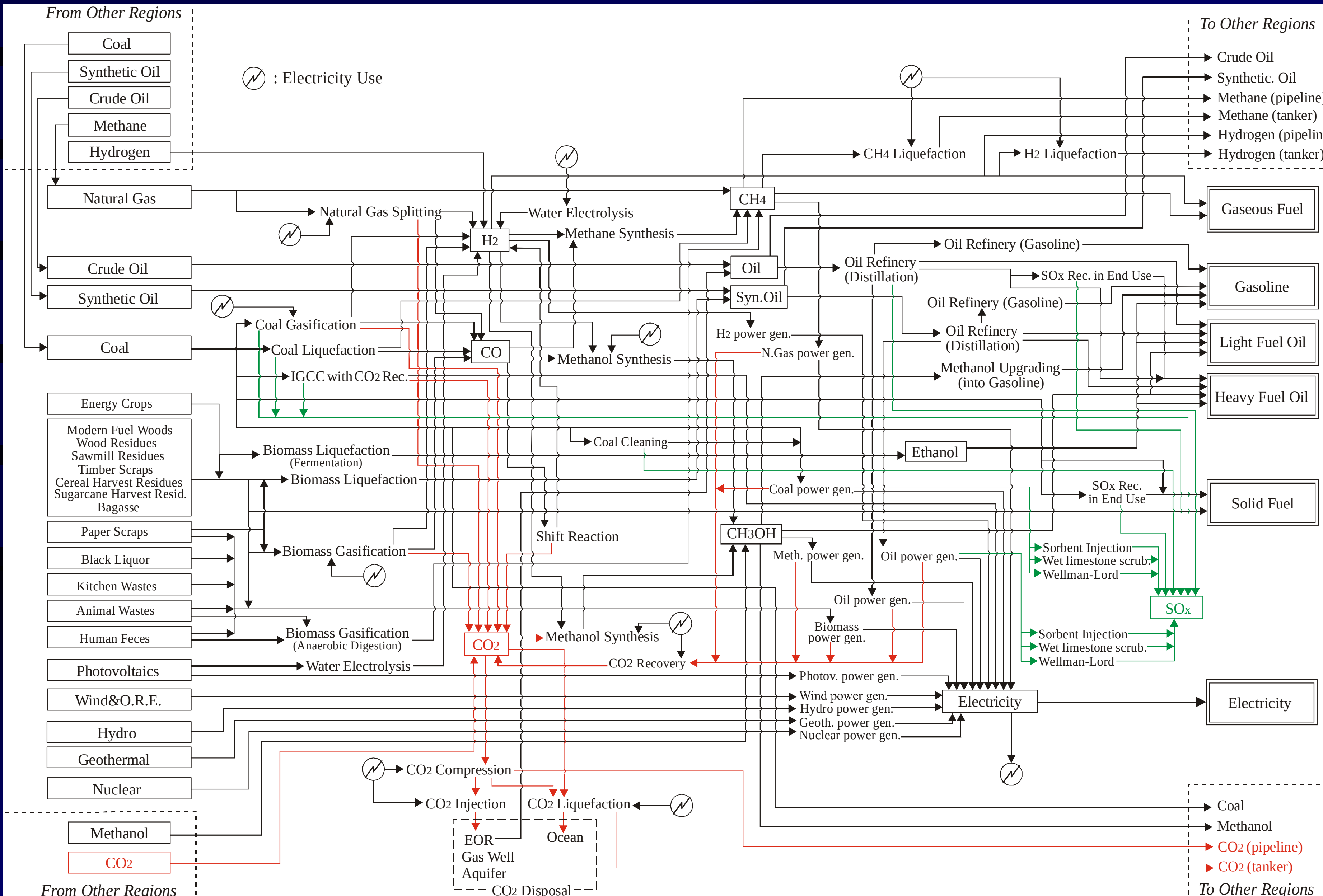
Integration of energy flow

			Intermediate inputs										Final demand			Output
			Non energy sectors (j)				Energy sectors (e')						Trade	Investment	Consumption	
			EIS	Y	AGR	SER	CRU	OTR	COL	GAS	OIL	ELE	M	I	C	Q
Int. inputs	Non-energy sectors (i)	EIS	$a_{ij}Q_{j,t}$				$b_{ie}EC_{e',t}$						$x_{i,t}-m_{i,t}$	$I_{i,t}$	$C_{i,t}$	$Q_{i,t}$
		Y														
		AGR														
		SER														
	Energy sectors	CRU	0				0				$EC_{CRU,OIL,t}$	0	$P_{e,t}\cdot E_{e,M,t}$	0	0	$EC_{e,t}$
		OTR									0	$EC_{e_s,ELE,t}$				
		COL	$EC_{s,j,t}=e_{sj}Q_{j,t}$												$EC_{s,C,t}$	
		GAS														
		OIL														
		ELE										0				
VADD	capital	K	$V_{j,t}=K_{j,t}+L_{j,t}$				$V_{e',t}$									
	labor	L														
Output		Q	$Q_{j,t}=Q_{i,t}$				$EC_{e',t}=EC_{e,t}$									

	Non energy sectors (j)				Energy flow						Trade	Consumption	Production	Prices
	EIS	Y	AGR	SER	CRU	OTR	COL	GAS	OIL	ELE				
CRU	0				0				$E_{CRU,OIL,t}$	0	$E_{e,M,t}$	0	$E_{e,t}$	$P_{e,t}$
OTR									0	$E_{e_s,ELE,t}$				
COL	$E_{s,j,t}$											$E_{s,C,t}$		
GAS														
OIL														
ELE										0				

Energy flow in DNE-21 model:

simplified structure will be imposed.



Aggregation of GTAP data into 18 regions and 18 non-energy sectors

18 regions

USA	USA	CAF	Middle African countries
CAN	Canada	SAF	South African countries
MCM	Middle American countries	JPN	Japan
BRA	Brazil	CHN	China, Hong kong, Taiwan
SAM	Peru, Argentina, Chile, Uruguay and other south American countries	IND	India
WEP	West and middle European countries	ASN	Asia NIES countries
EEP	Hungary, Poland and other east European countries	TME	Turkey and Middle-East countries
FSU	Former USSR	ANZ	Australia, New Zealand and Pacific Island countries
NAF	North and Middle African countries	XAP	Other countries

Aggregation of GTAP data into 18 regions and 18 non-energy sectors

18 non-energy sectors

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

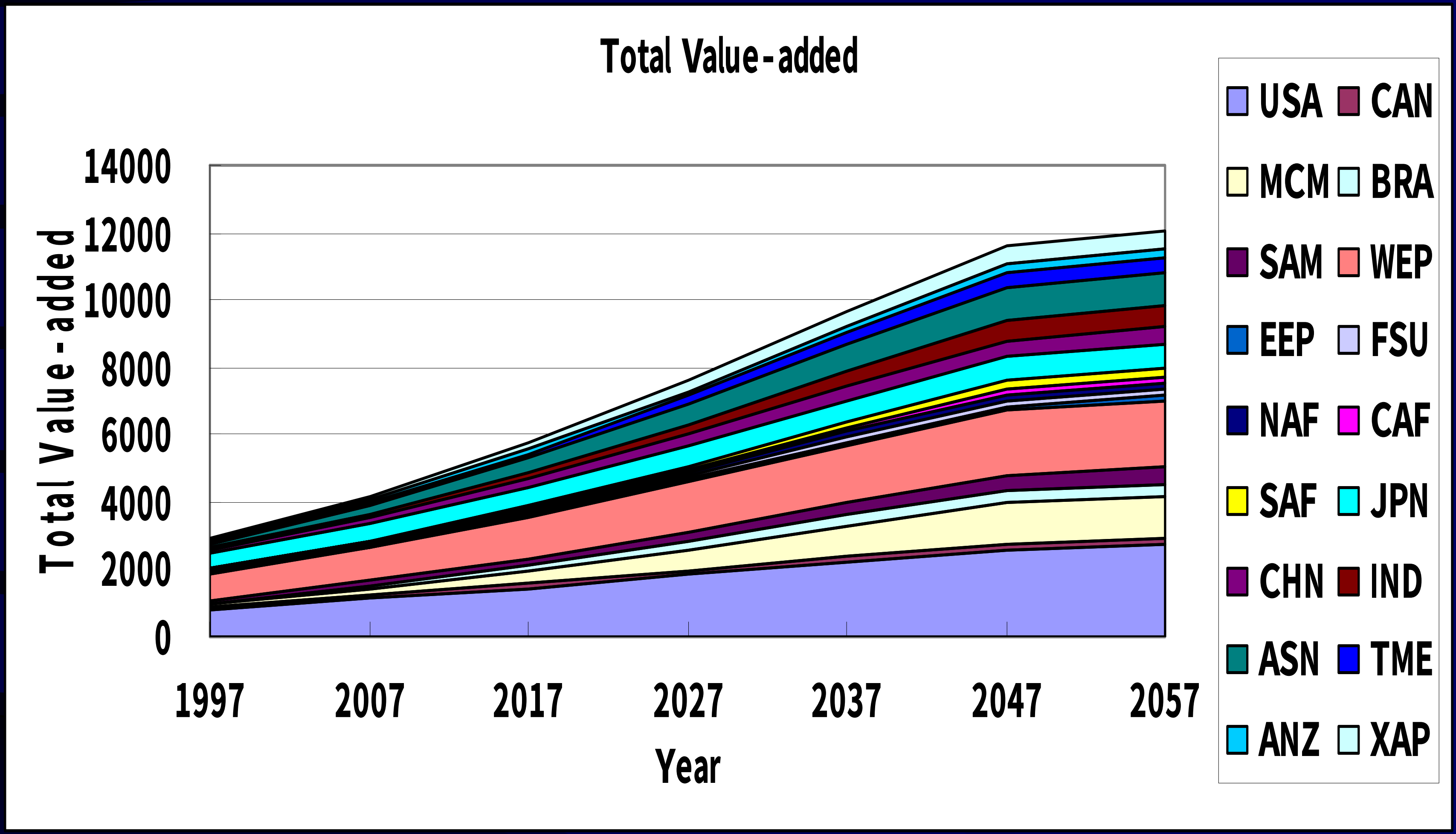
Current Stage：

Two preliminarily dynamic models are developed.

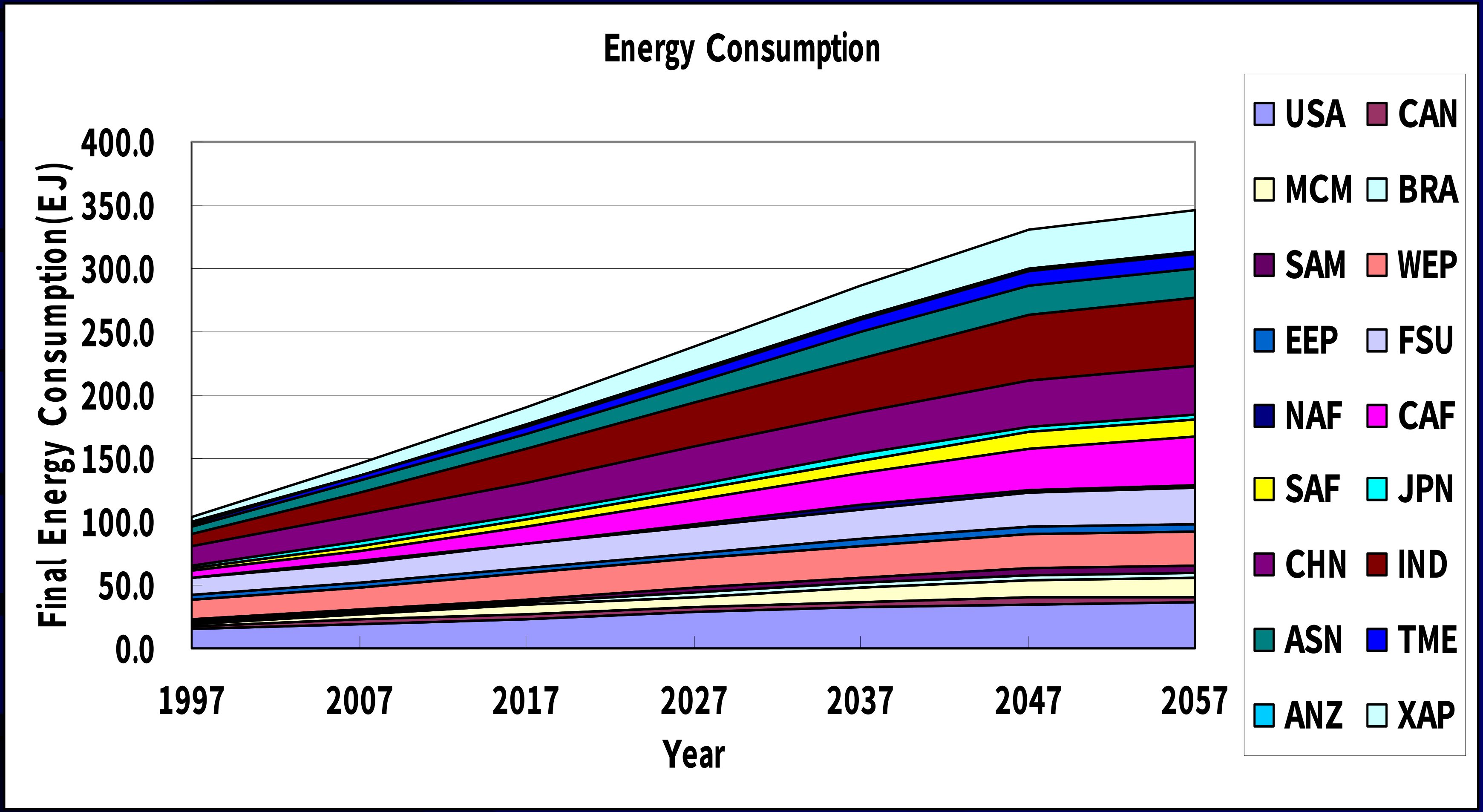
(1)18-region and 18-sector model with 2 energy sectors (Primary and secondary)

(2) 1-region and 18-sector model with 6 energy sources and 4 power generation technologies

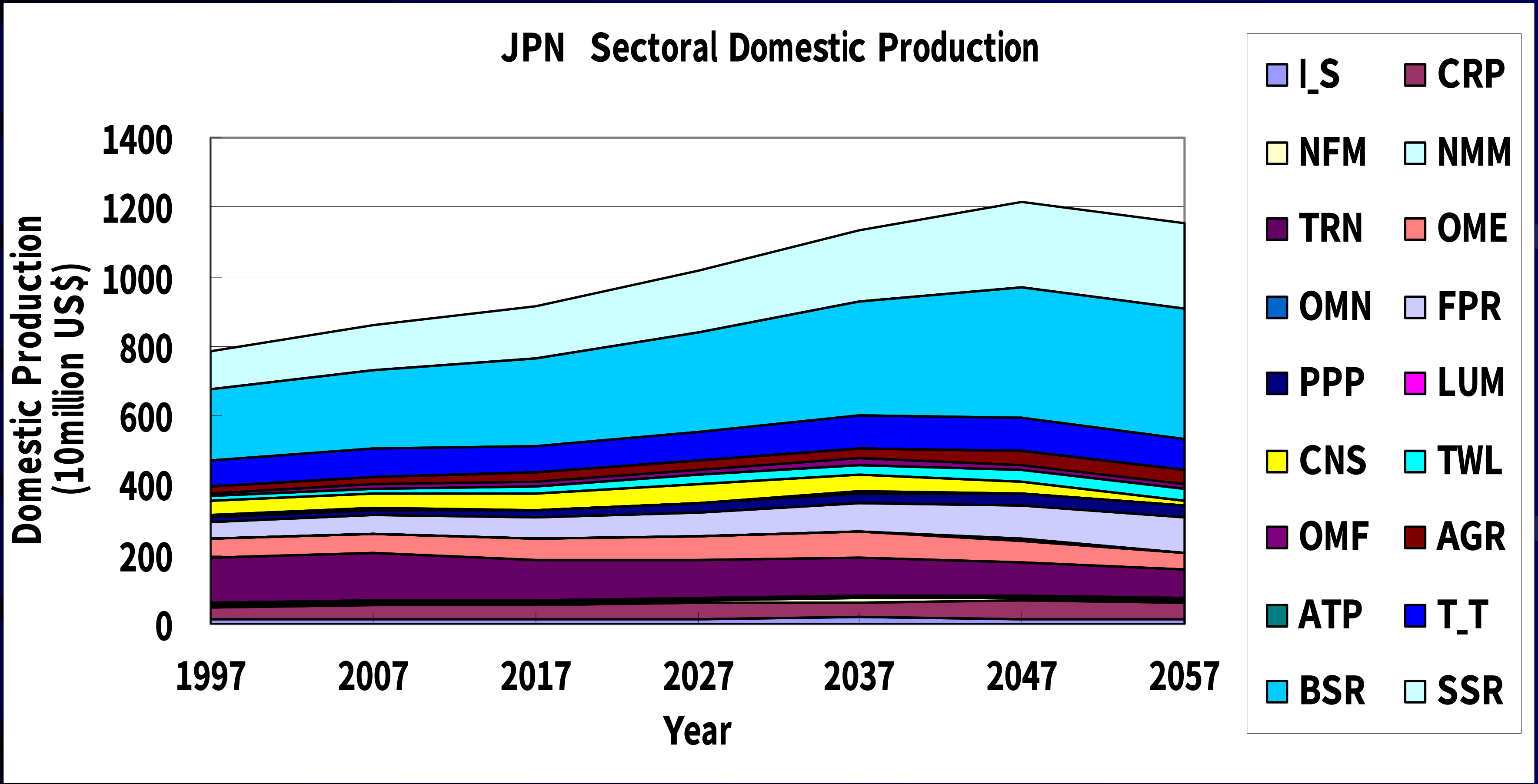
These two are being integrated.



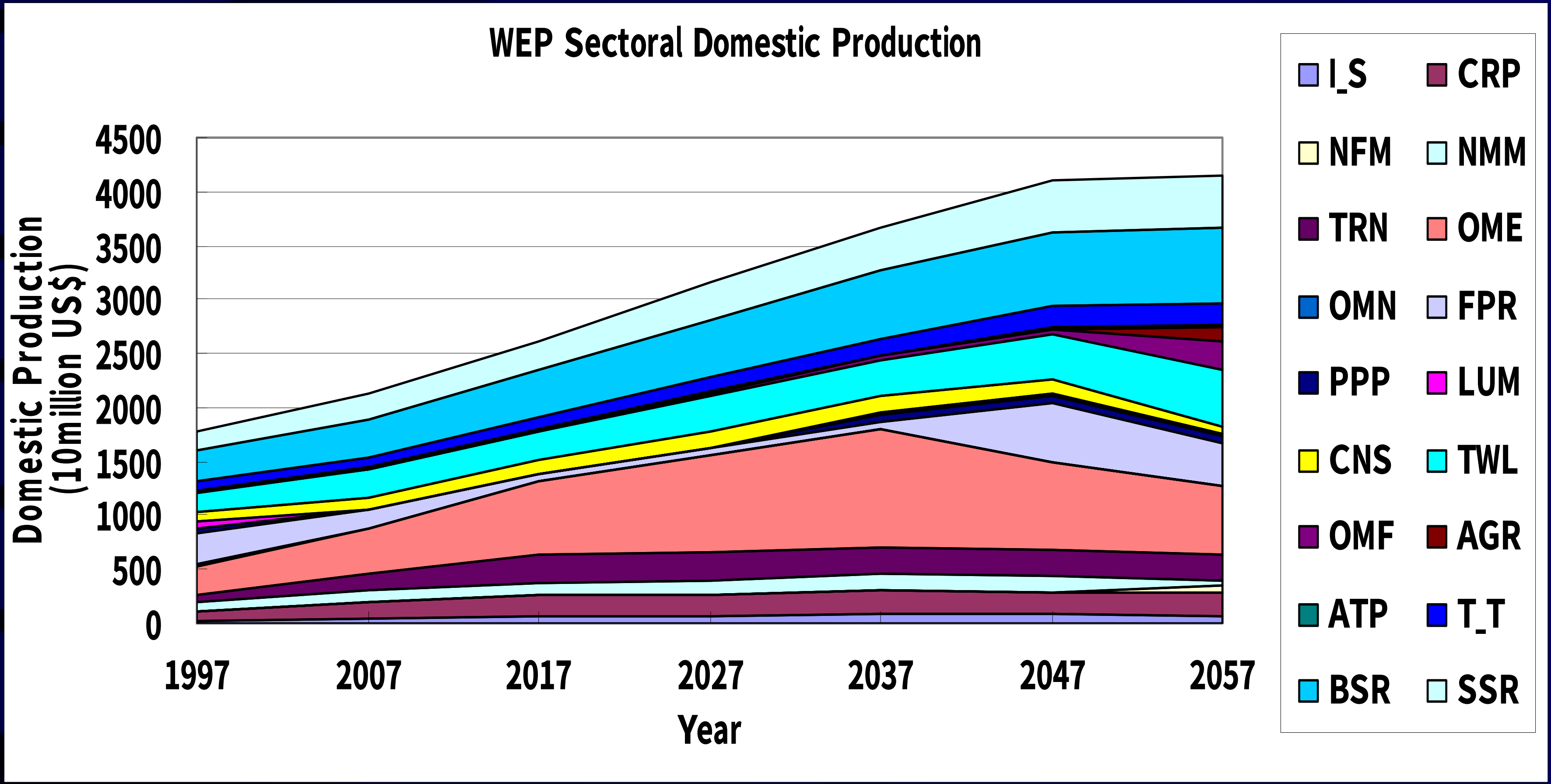
Preliminarily Simulation Results: GDP
18 region - 18 sector with 2 energy input model



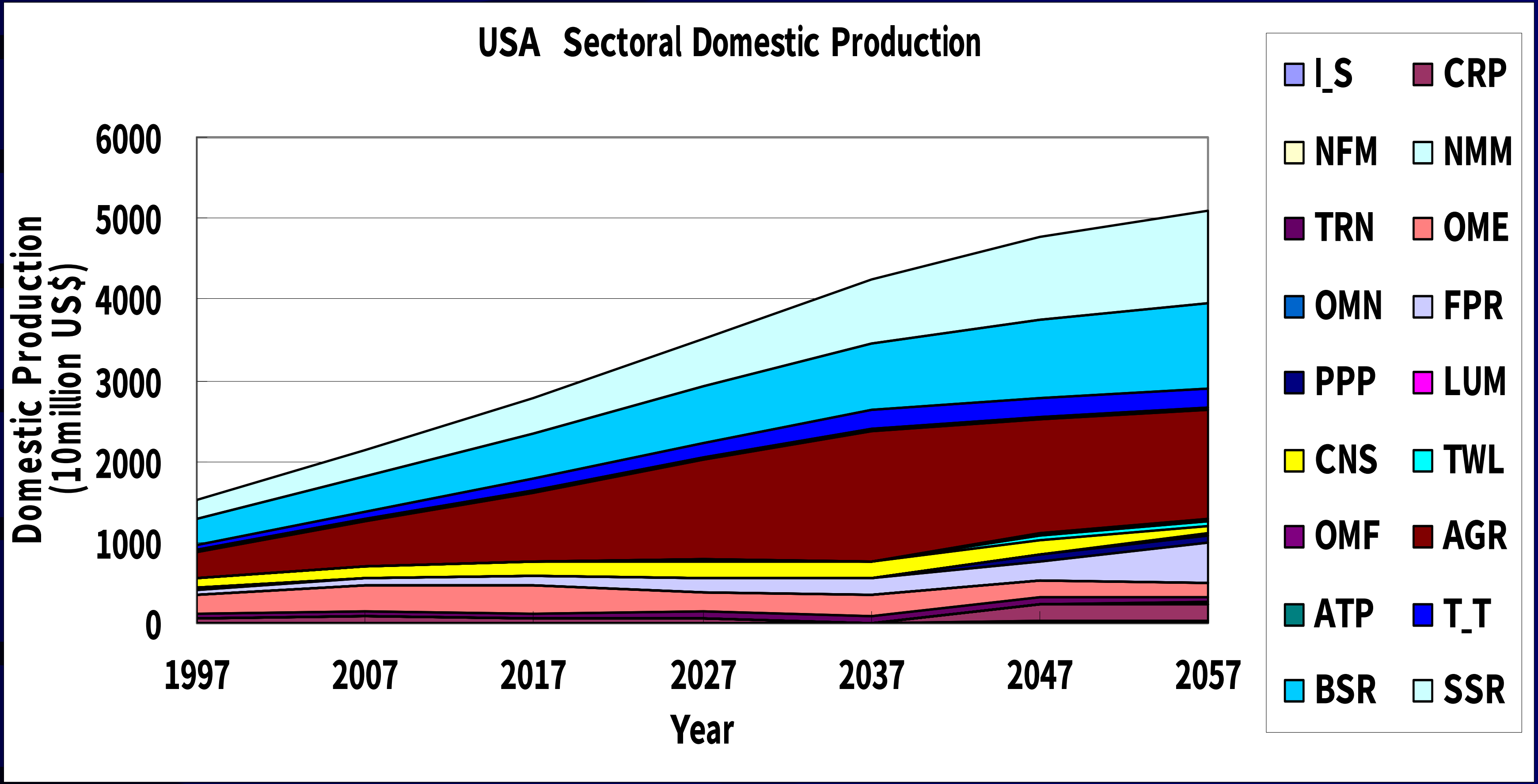
Preliminarily Simulation Results:
Final Energy Concumption
18 region - 18 sector with 2 energy input model



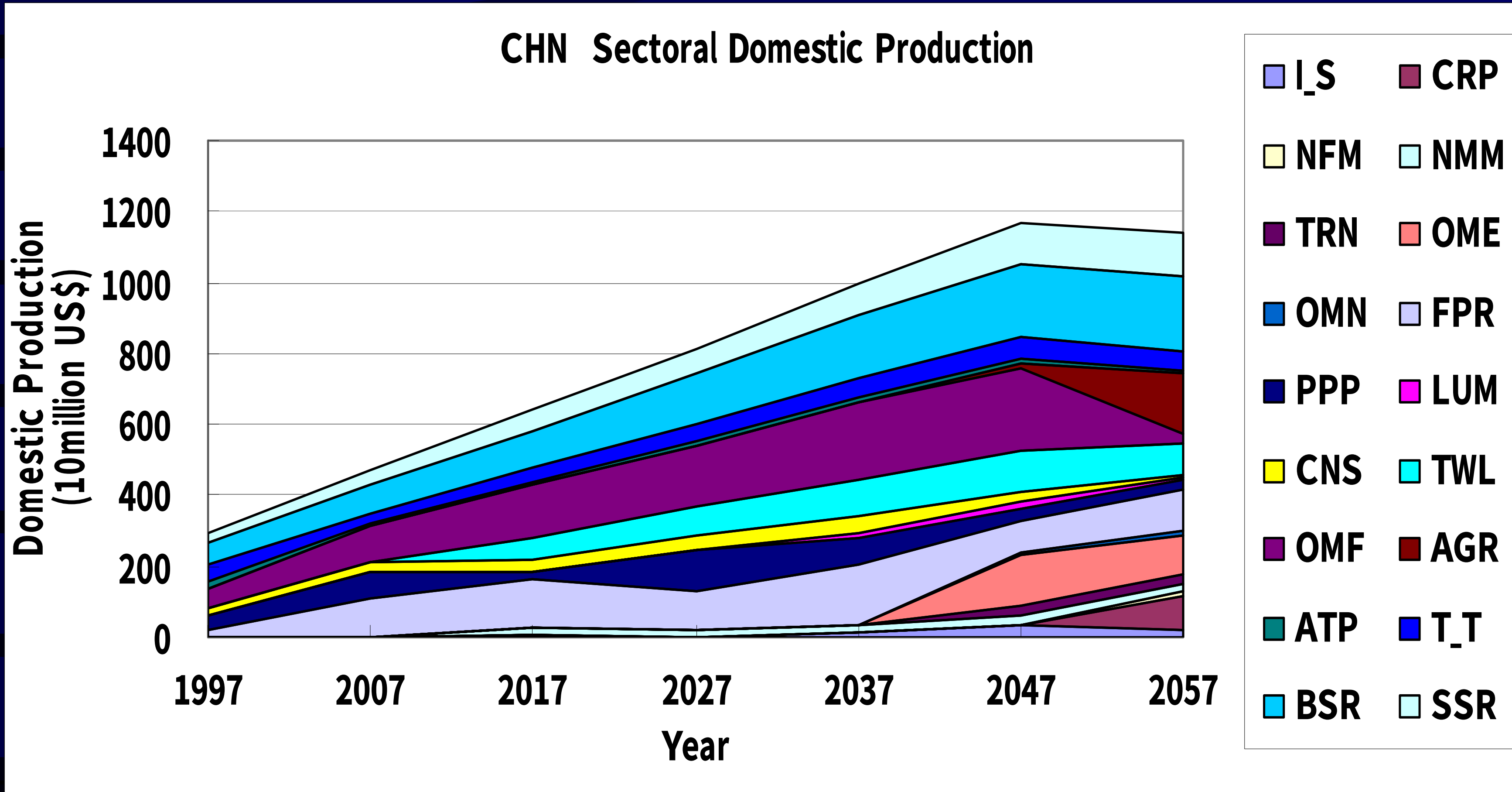
Preliminarily Simulation Results:
Outputs by sector (Japan)
18 region - 18 sector with 2 energy input model



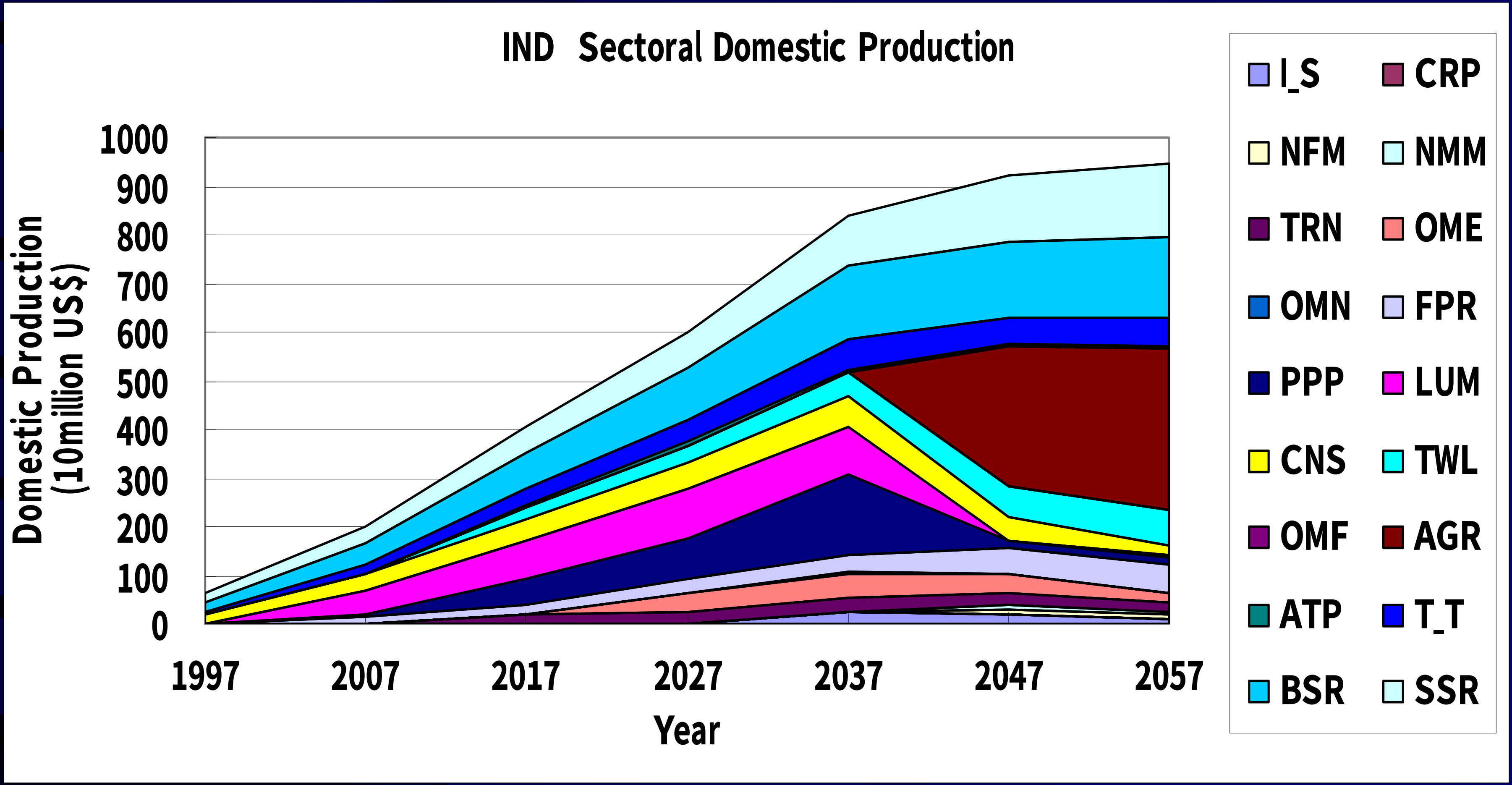
Preliminarily Simulation Results:
Outputs by sector (WEP)
18 region - 18 sector with 2 energy input model



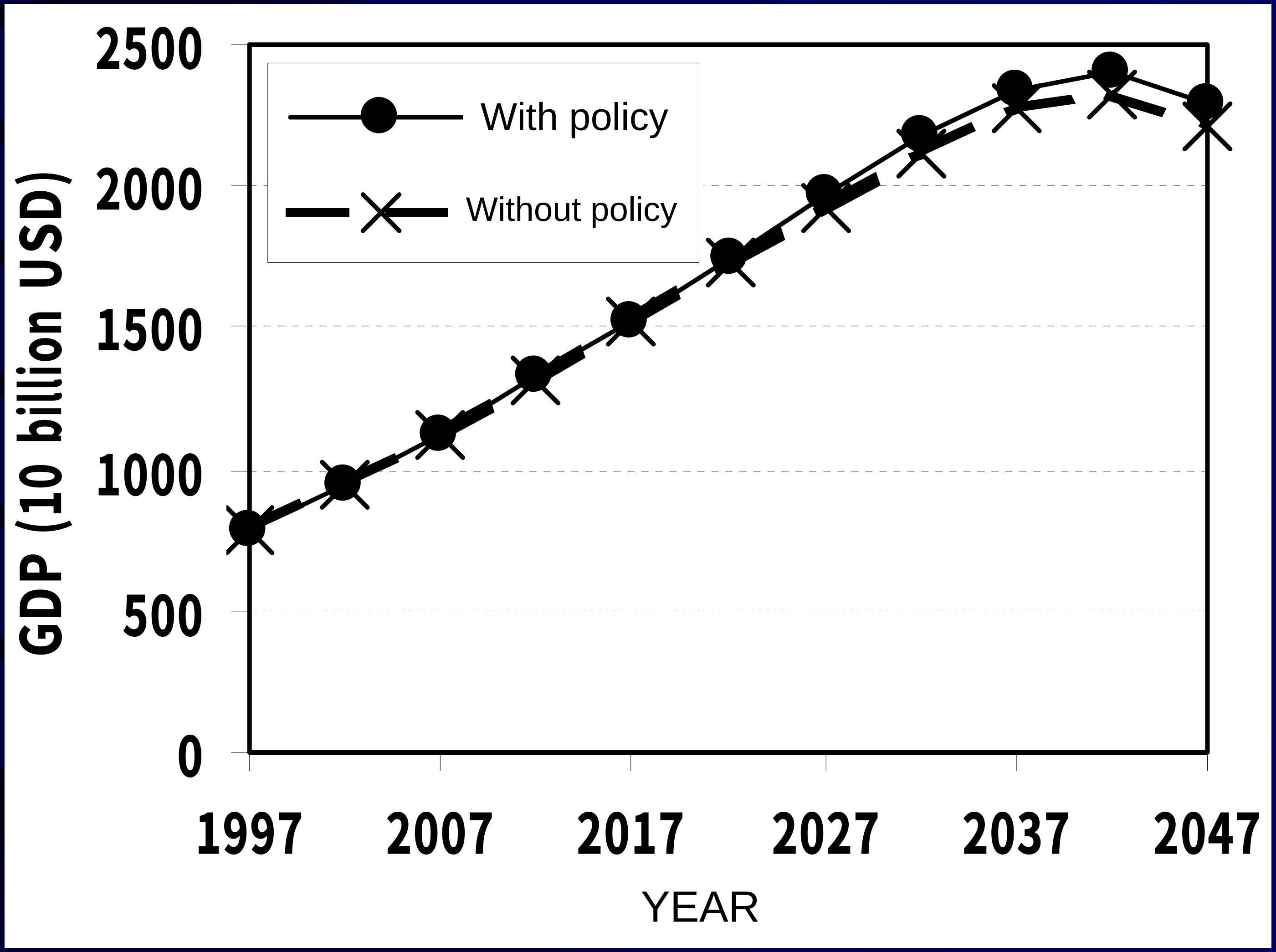
Preliminarily Simulation Results:
Outputs by sector (USA)
18 region - 18 sector with 2 energy input model



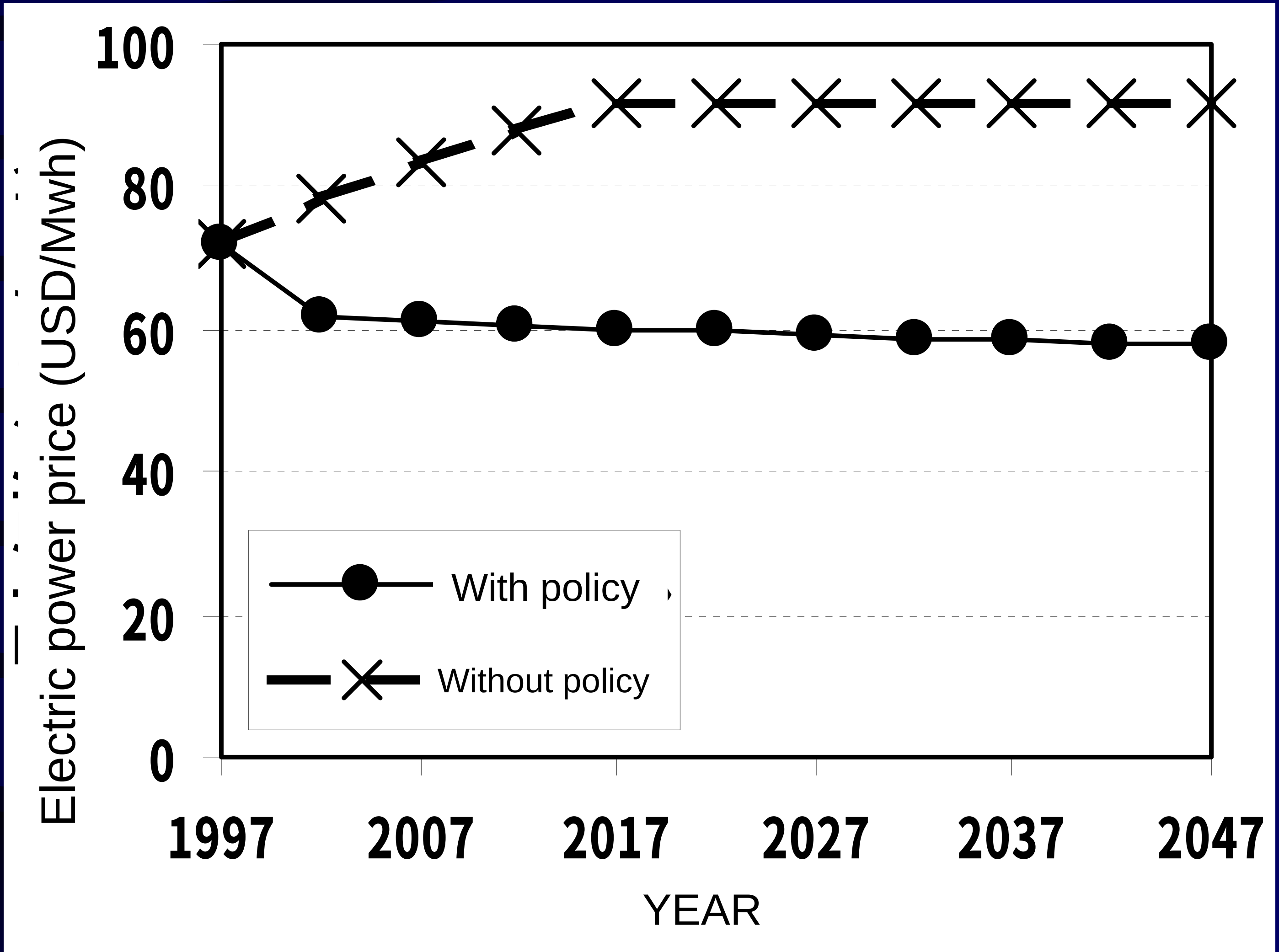
Preliminarily Simulation Results:
Outputs by sector (CHN)
18 region - 18 sector with 2 energy input model



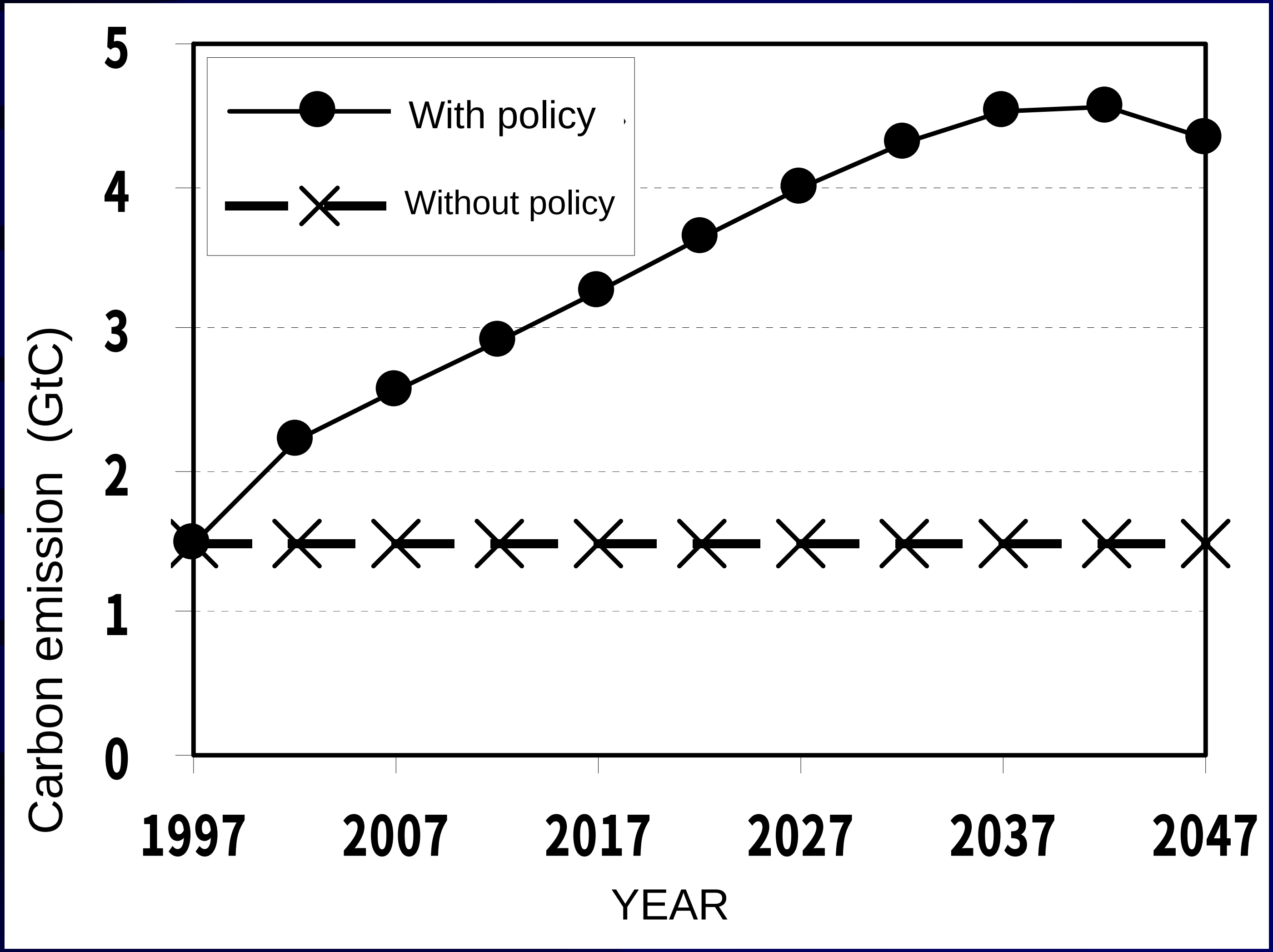
Preliminarily Simulation Results:
Outputs by sector (India)
18 region - 18 sector with 2 energy input model



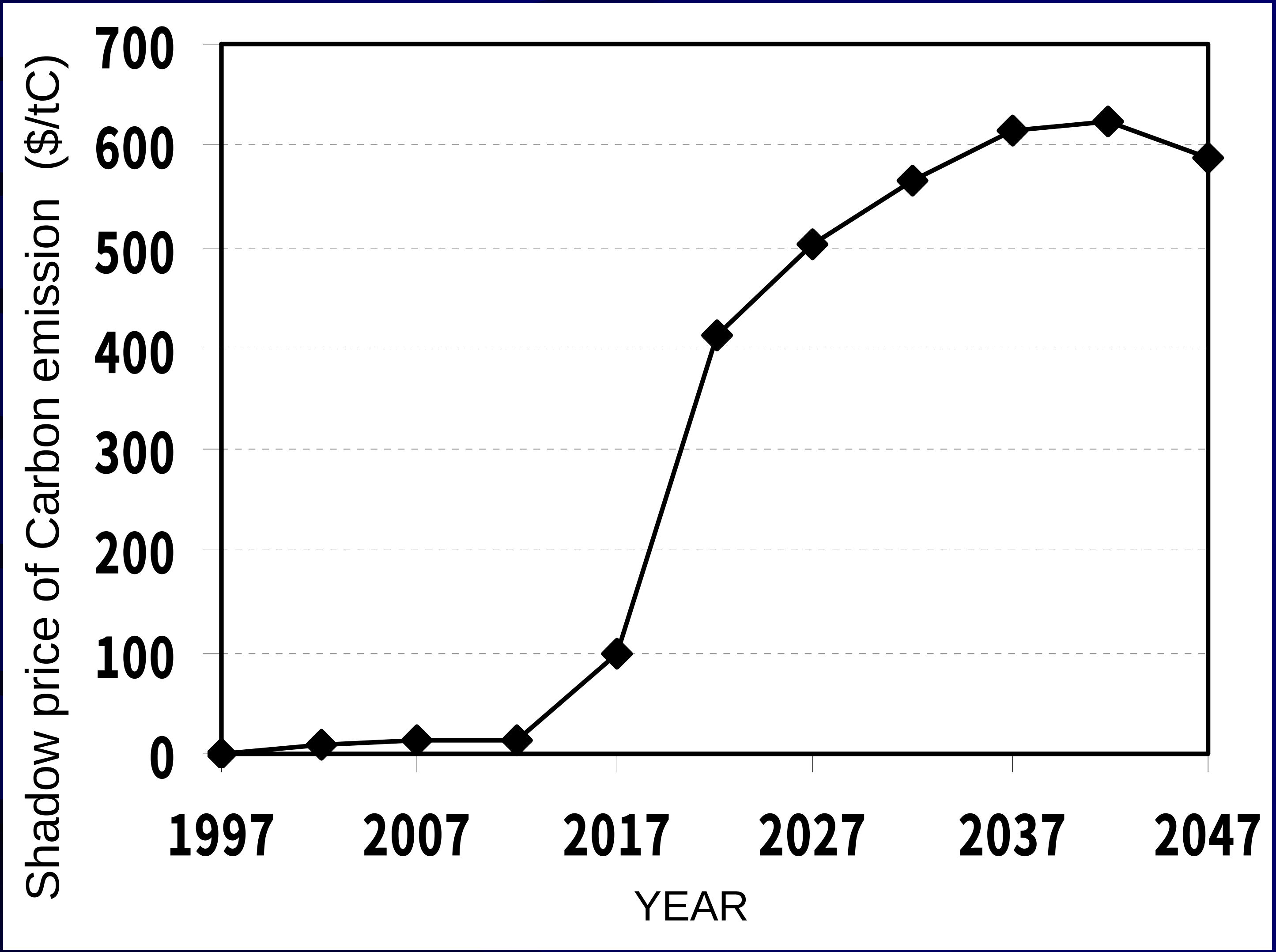
Preliminarily Simulation Results:GDP (USA)
1 region - 18 sector with 6 energy input model
with and without carbon emission stabilization policy



Preliminarily Simulation Results:electric power price (USA)
1 region - 18 sector with 6 energy input model
with and without carbon emission stabilization policy

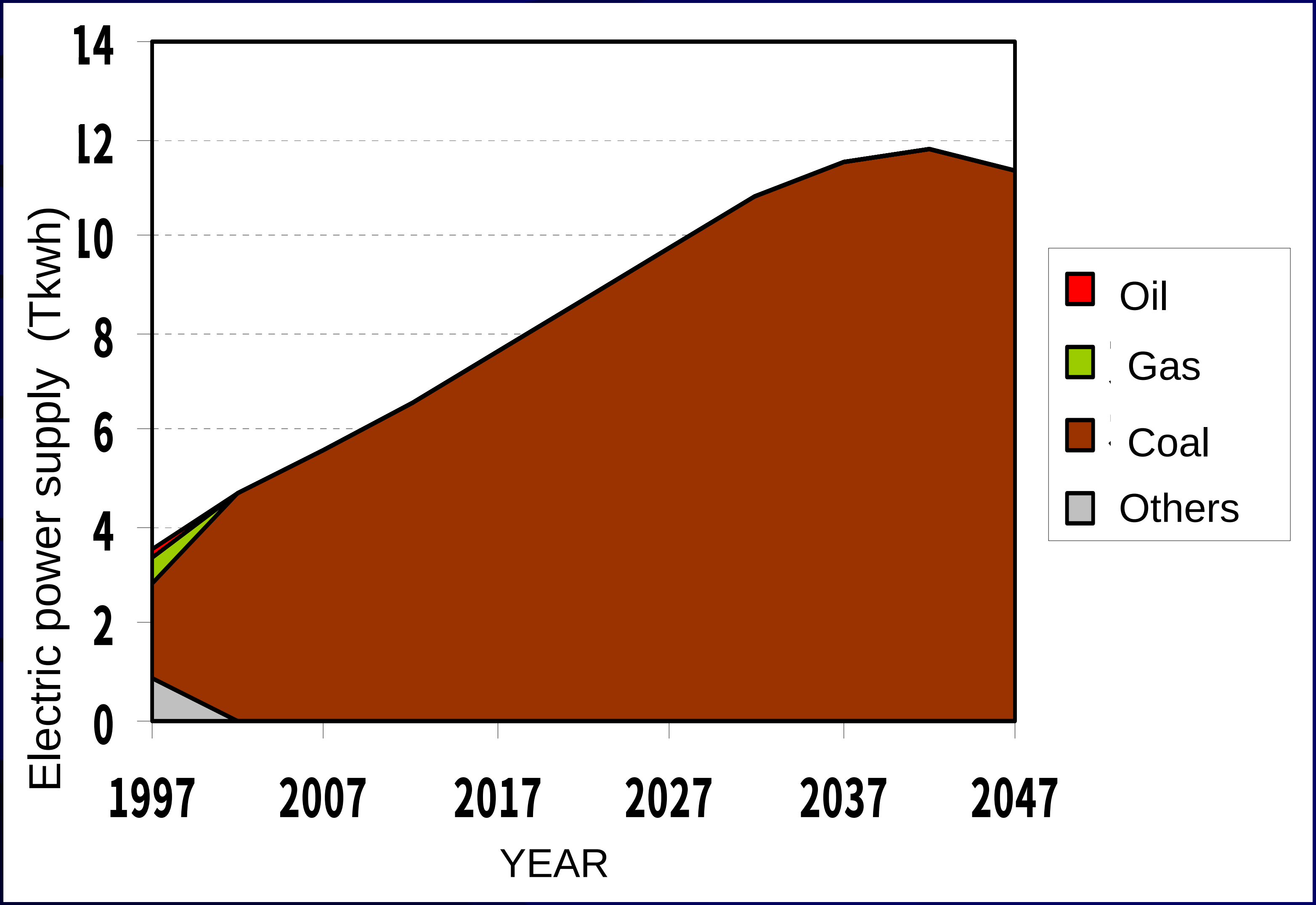


Preliminarily Simulation Results:carbon emission (USA)
1 region - 18 sector with 6 energy input model
with and without carbon emission stabilization policy



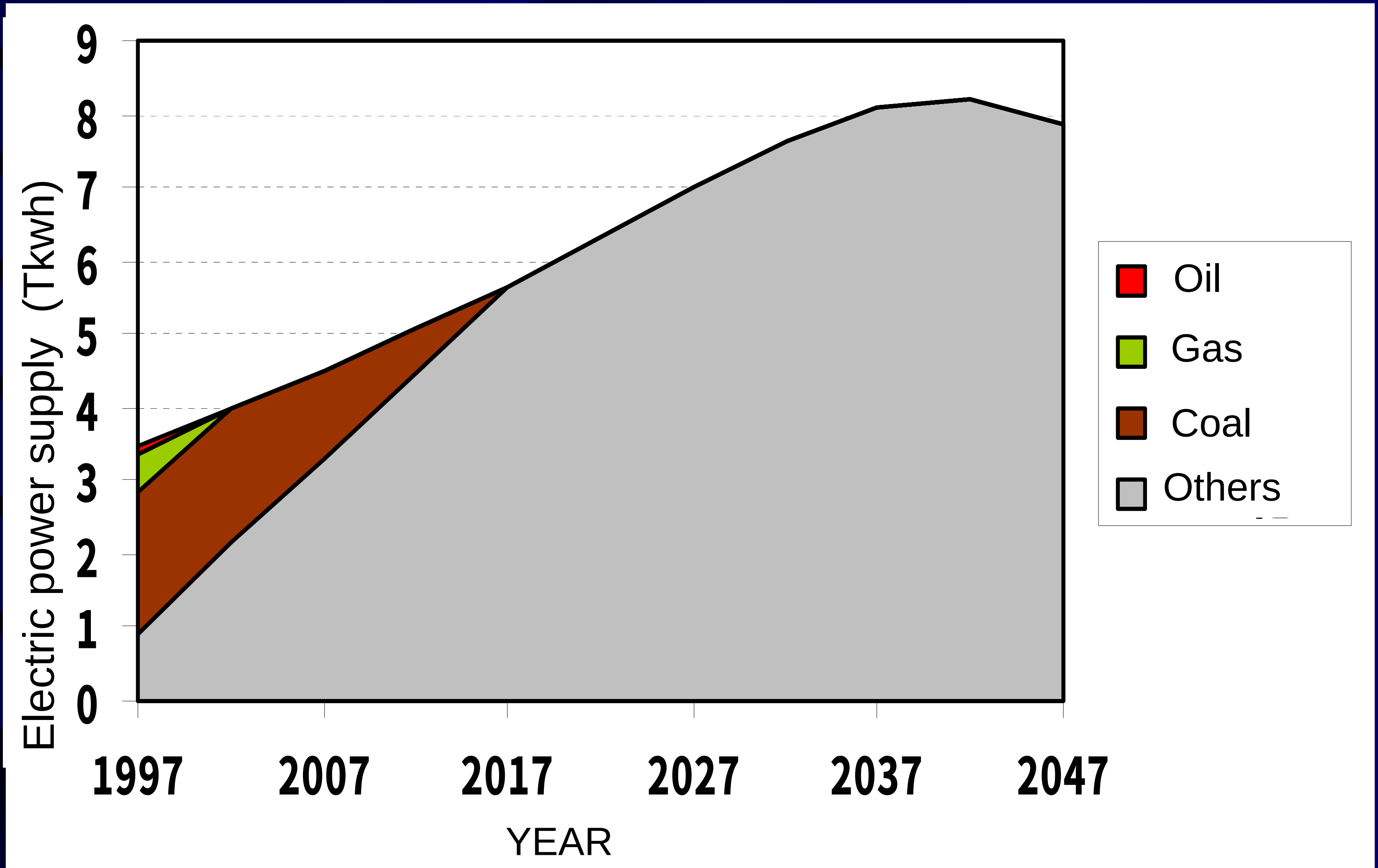
Preliminarily Simulation Results:

Shadow price of carbon emission (USA)
1 region - 18 sector with 6 energy input model
with and without carbon emission stabilization policy



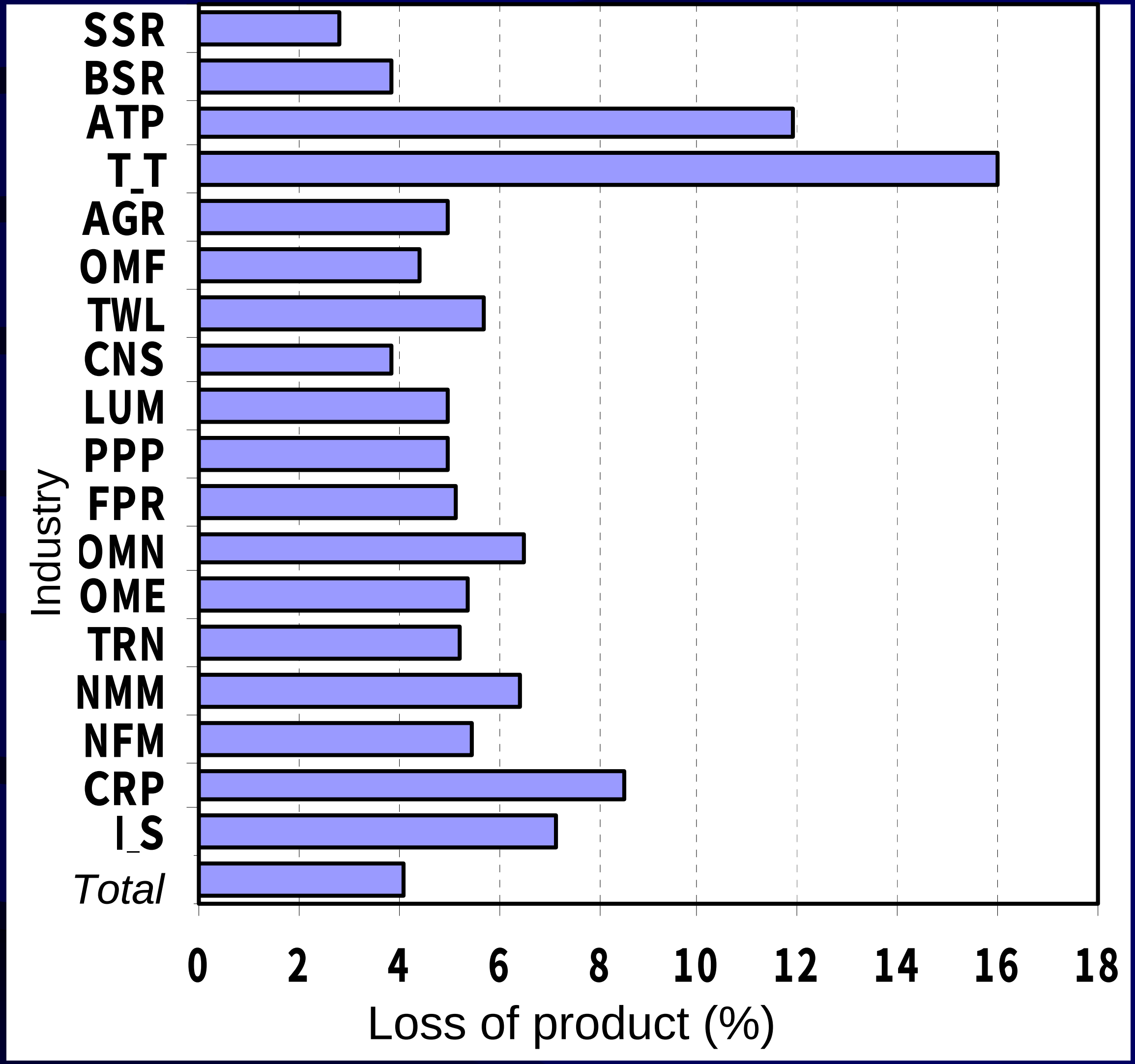
Preliminarily Simulation Results:

Power generation mix without carbon policy (USA)
1 region - 18 sector with 6 energy input model
with and without carbon emission stabilization policy



Preliminarily Simulation Results:

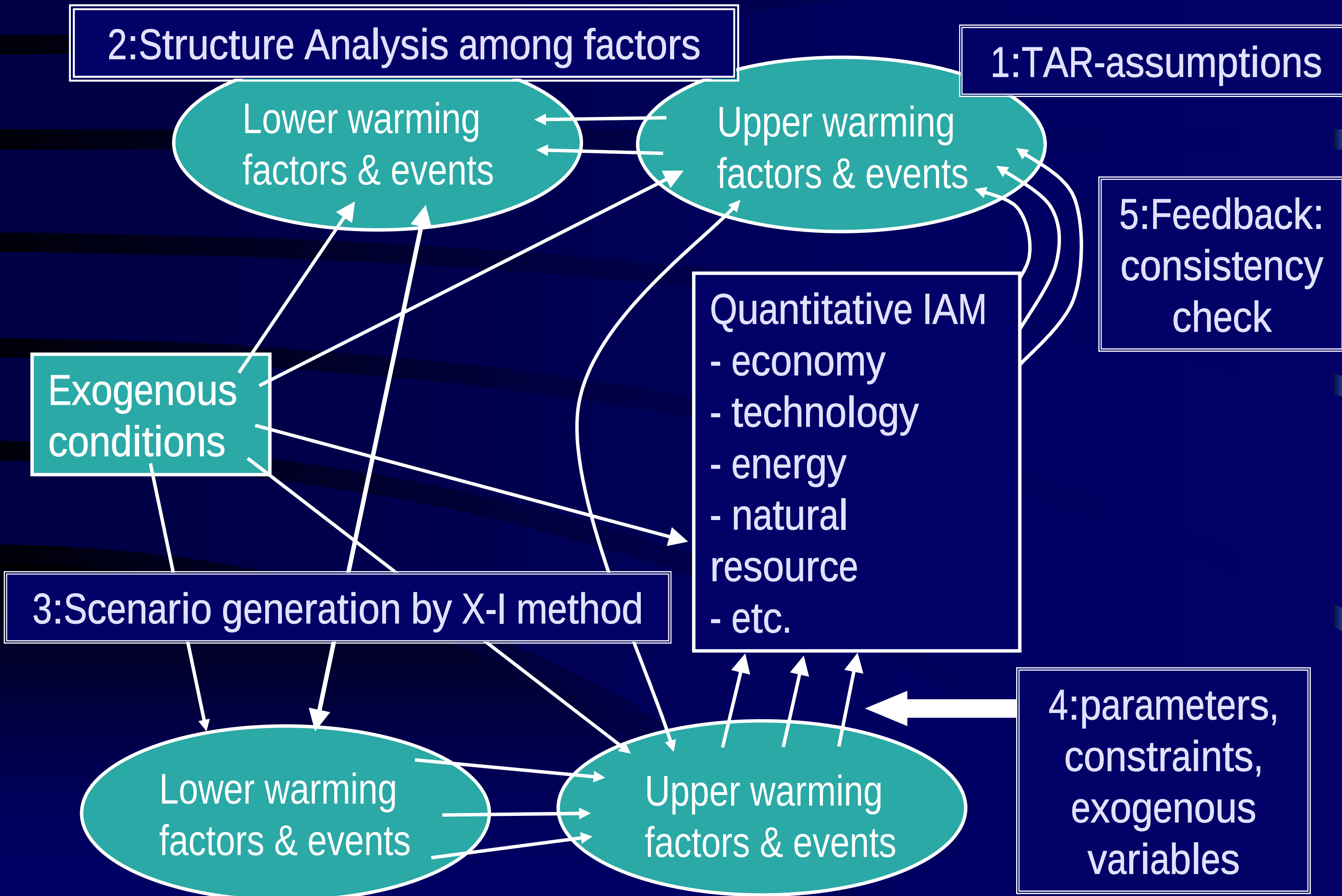
Power generation mix with carbon policy (USA)
1 region - 18 sector with 6 energy input model
with and without carbon emission stabilization policy



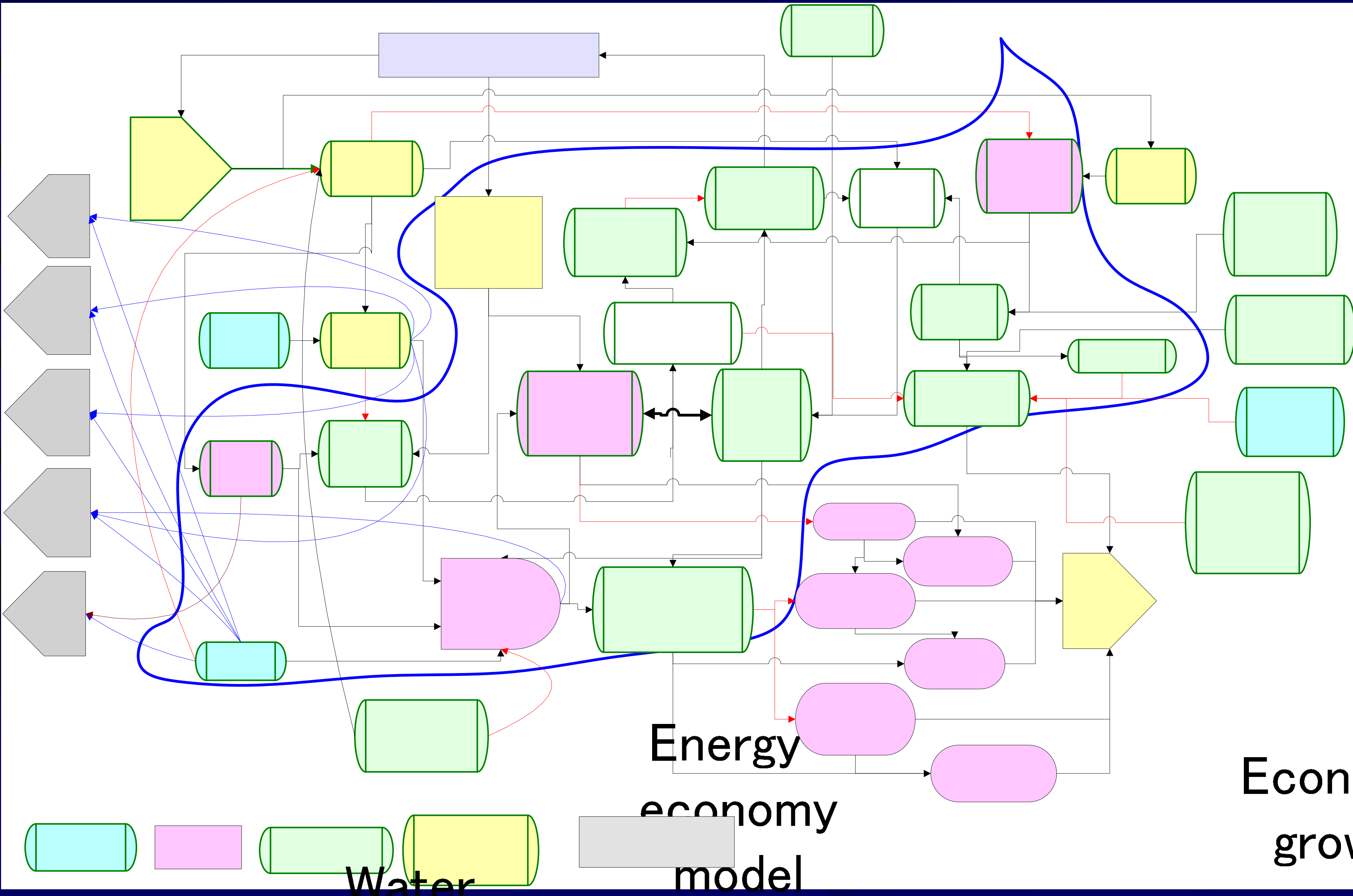
Preliminarily Simulation Results:

Impacts of carbon policy; loss of sector products in 2047 (USA)
1 region - 18 sector with 6 energy input model
with and without carbon emission stabilization policy

Integration : Scenario Generation and Simulations



Structure Analysis for the Narrative Scenario Generation



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 $\{\boldsymbol{\pi}_k\}$.

Scenario Generation using X-I method -3

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

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

π_k :n-dimensional probability $\mathrm{P}\left(\mathrm{d}_1^k, \mathrm{d}_2^k, \Lambda\ \mathrm{d}_n^k\right)\ \left(\mathrm{k}=1,2,\Lambda\ 2^n\right)$.

$d_i^k = 1$ 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

Scenario A   Scenario B

upper:occurrence state lower: range of probability

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

Dynamic scenario sequences from 1990-2010

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

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.**