Measuring the Contribution of New and Renewable Energy R&D to Slowing Down CO_2 Emissions in Taiwan with an Integrated Modeling Approach

Shih-Mo Lin, Chung-Chaing Feng, Jin-Xu Lin
Han-Pang Su, and Fu-Kuang Ko

Center for Applied Economic Modeling
Chung Yuan Christian University, Taiwan

Outline

- **Motivations**
- **Objective**
- **Energy Situation of Taiwan**
- **Renewable R&D and the Economy**
- **Methodology**
- **Results and Analysis**
- **Conclusions**

Motivations

- **Energy is an important input to the economy and Taiwan relies heavily on imported energy. As such, how to maintain a stable supply of energy at a stable price has become an extremely important policy issue in Taiwan.**
- **To reduce the reliance on imported energy and the level of CO_2 emission, developing new and renewable energies has become one of the primary energy policies of the Taiwanese government.**

Motivations

- **Bureau of Energy (BOE) has pushed the legislation of "Renewable Energy Development Bill". According to the Bill, the capacity of renewable energies will be 12% share of the national power installation capacity by 2020.**
- **Government has a vital role to play in the development of renewable energy technology, and that whatever investments the government makes now should have significant returns in the future.**

Purposes of Study

- To explore whether with a reasonable level of R&D investment and the learning process associated with the production and adoption of renewable energy technology, renewable energy technology development is cost-effective and has significant environmental benefit.
- Integrated modeling approach.

Overview of energy and economic situation of Taiwan

Sources:

Directorate General of Budget, Accounting and Statistics, Executive Yuan, R.O.C.

Ministry of Economic Affairs, R.O.C.

Bureau of Energy, Ministry of Economic Affairs, R.O.C.

Ministry of Finance, R.O.C.

1. 重要經濟指標表(續)
Economic Indicators (Cont.)

年別 Year	經濟成長率 Economic Growth Rate % (real GDP)	工業成長率 Industrial Growth Rate %	農業成長率 Agricultural Growth Rate %	對外貿易 (百萬美元) Foreign Trade (million US$)		
				合計 Total	進口 Imports	出口 Exports
1987	12.66	12.18	6.31	88,662	34,983	53,679
1988	8.04	5.01	1.00	110,340	49,673	60,667
1989	8.45	4.43	-0.58	118,569	52,265	66,304
1990	5.70	0.81	2.26	121,931	54,716	67,214
1991	7.58	6.86	1.77	139,039	62,861	76,178
1992	7.85	6.00	-2.25	153,477	72,007	81,470
1993	6.90	4.68	5.07	162,153	77,061	85,092
1994	7.39	6.22	-4.21	178,398	85,349	93,049
1995	6.49	4.97	2.71	215,209	103,550	111,659
1996	6.30	3.06	-0.48	220,503	102,922	117,581
1997	6.59	5.36	-1.94	239,126	114,955	124,170
1998	4.55	2.62	-6.32	217,825	105,230	112,595
1999	5.75	5.38	2.73	234,930	111,196	123,733
2000	5.77	5.77	1.21	292,682	140,732	151,950
2001	-2.17	-7.51	-1.95	234,285	107,971	126,314
2002	4.64	7.29	4.74	248,562	113,245	135,317
2003	3.50	4.00	-0.06	278,611	128,010	150,601
2004	6.15	8.94	-4.09	351,128	168,758	182,370
2005	4.16	6.34	-8.07	381,046	182,614	198,432
2006	4.89	7.04	6.09	426,715	202,698	224,017
2007	5.70	9.16	-2.91	466,069	219,347	246,723

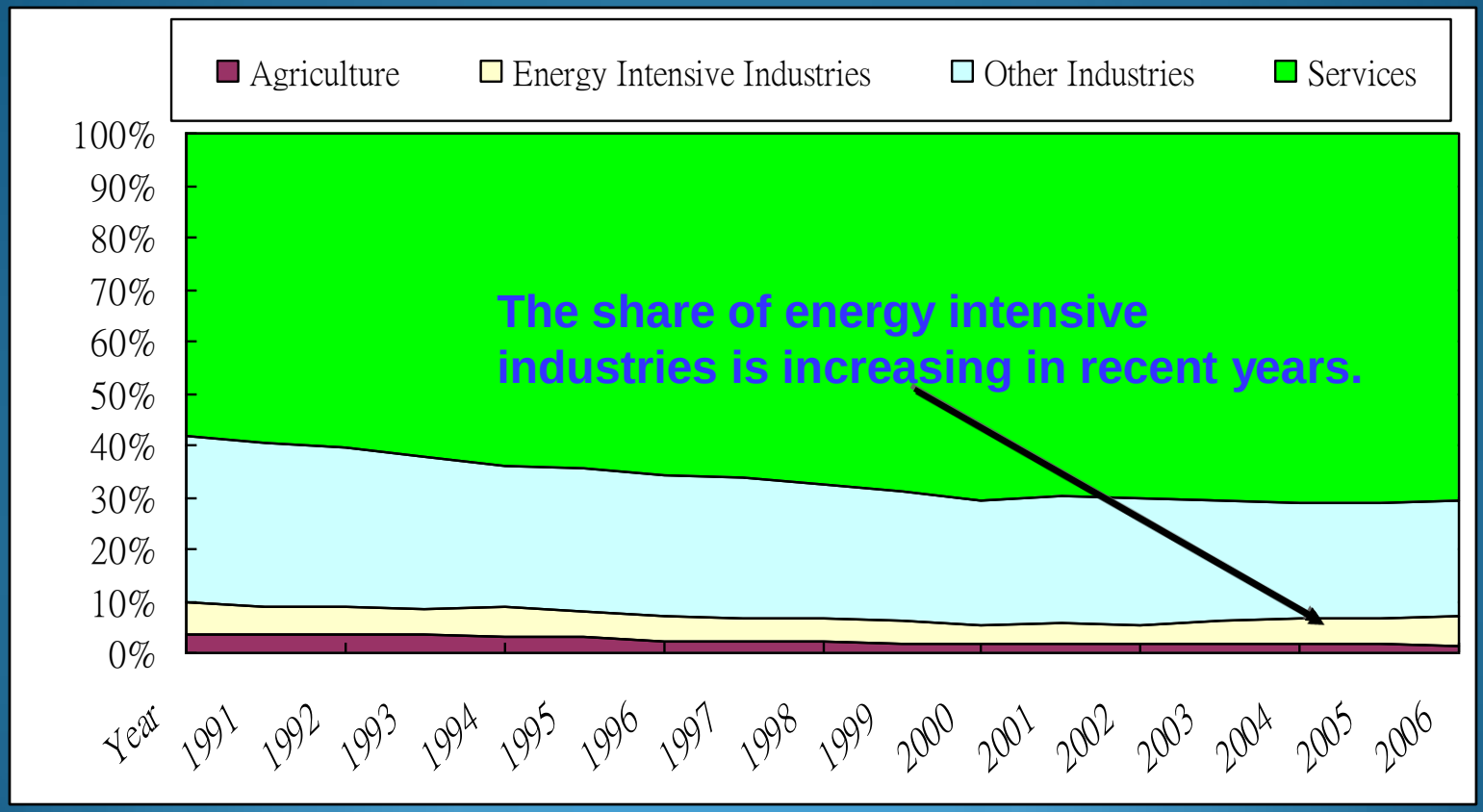
註：經濟成長率、工業成長率及農業成長率按九十年價格計算

Source： The economic, industrial and agricultural growth rate are calculated by its value-added at 2001 contant prices.

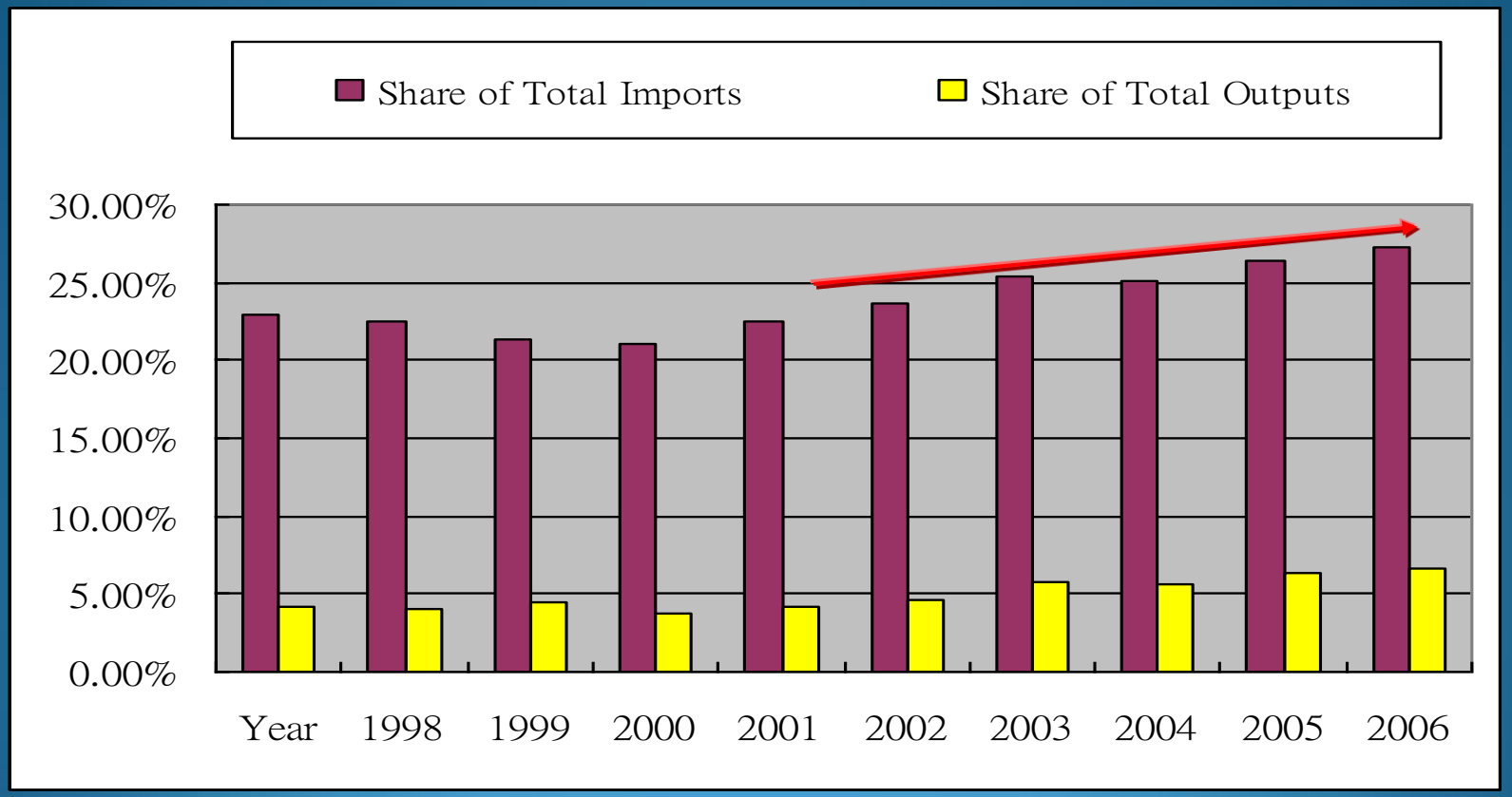
1. 重要經濟指標表(續)
Economic Indicators (Cont.)

年別 Year	產業結構(%) Structure of Domestic Production				物價指數 (民國90年=100) Price Index (2001=100)	
	合計 Total	農業 Agriculture	工業 Industry	服務業 Services	躉售 Wholesale Prices	消費者 Consumer Prices
1987	100.00	5.31	46.67	48.02	99.47	70.40
1988	100.00	5.04	44.84	50.13	97.91	71.30
1989	100.00	4.90	42.31	52.79	97.55	74.45
1990	100.00	4.18	41.23	54.59	96.96	77.52
1991	100.00	3.79	41.07	55.14	97.12	80.33
1992	100.00	3.60	40.08	56.33	93.55	83.92
1993	100.00	3.64	39.35	57.00	95.90	86.39
1994	100.00	3.51	37.71	58.77	97.98	89.93
1995	100.00	3.47	36.38	60.15	105.21	93.23
1996	100.00	3.05	32.42	64.53	104.15	96.10
1997	100.00	2.42	31.88	65.70	103.68	96.96
1998	100.00	2.36	31.22	66.42	104.30	98.60
1999	100.00	2.43	29.90	67.66	99.55	98.77
2000	100.00	1.98	29.09	68.93	101.36	100.01
2001	100.00	1.85	27.62	70.53	100.00	100.00
2002	100.00	1.74	28.28	69.98	100.05	99.80
2003	100.00	1.66	27.96	70.38	102.53	99.52
2004	100.00	1.64	27.57	70.79	109.74	101.13
2005	100.00	1.66	27.05	71.29	110.41	103.46
2006	100.00	1.62	26.84	71.54	116.64	104.08
2007	100.00	1.45	27.50	71.06	123.46	105.80

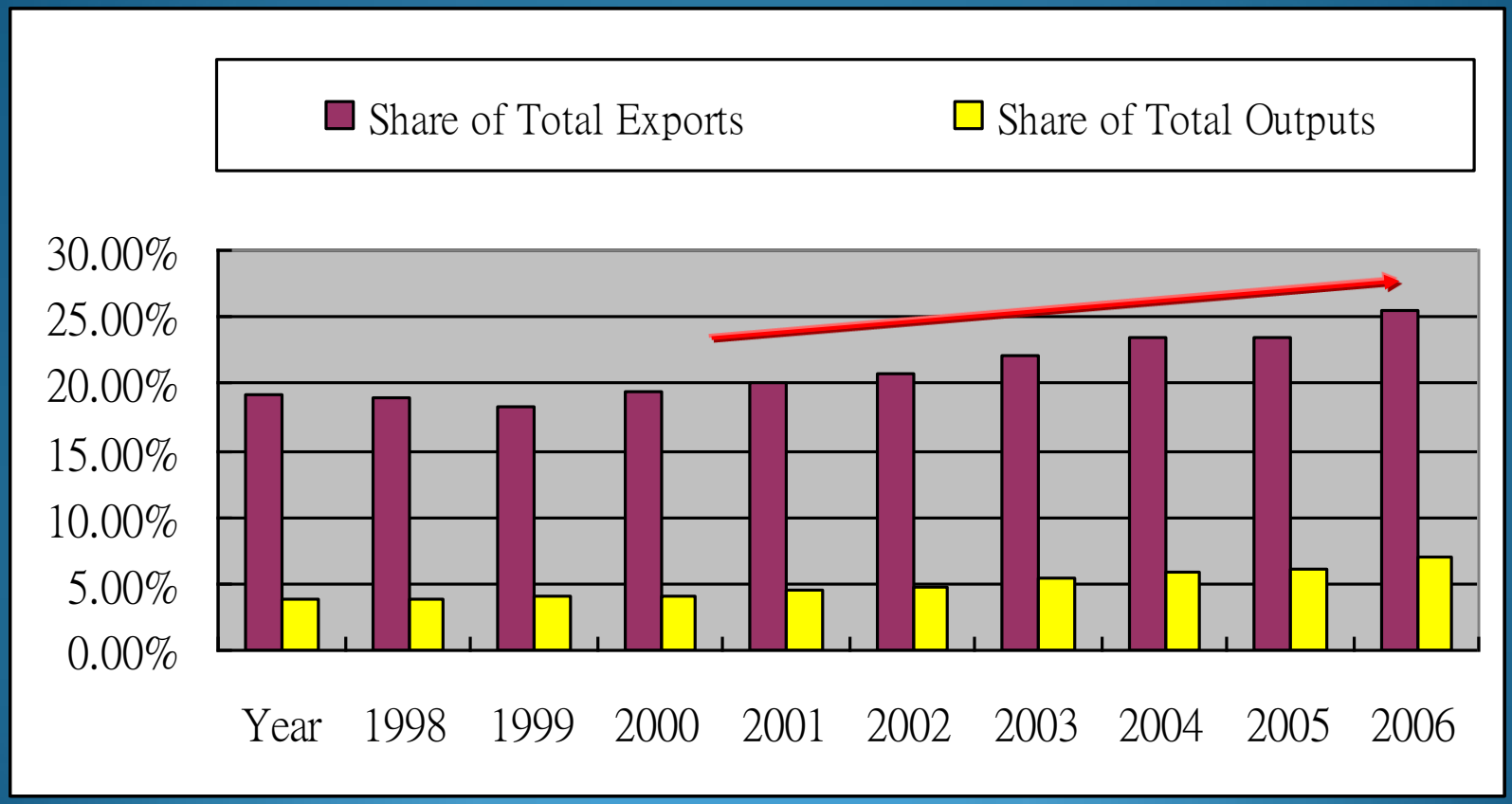
Industrial Structure (Constant Price)



Import of Energy Intensive Products



Export of Energy Intensive Products

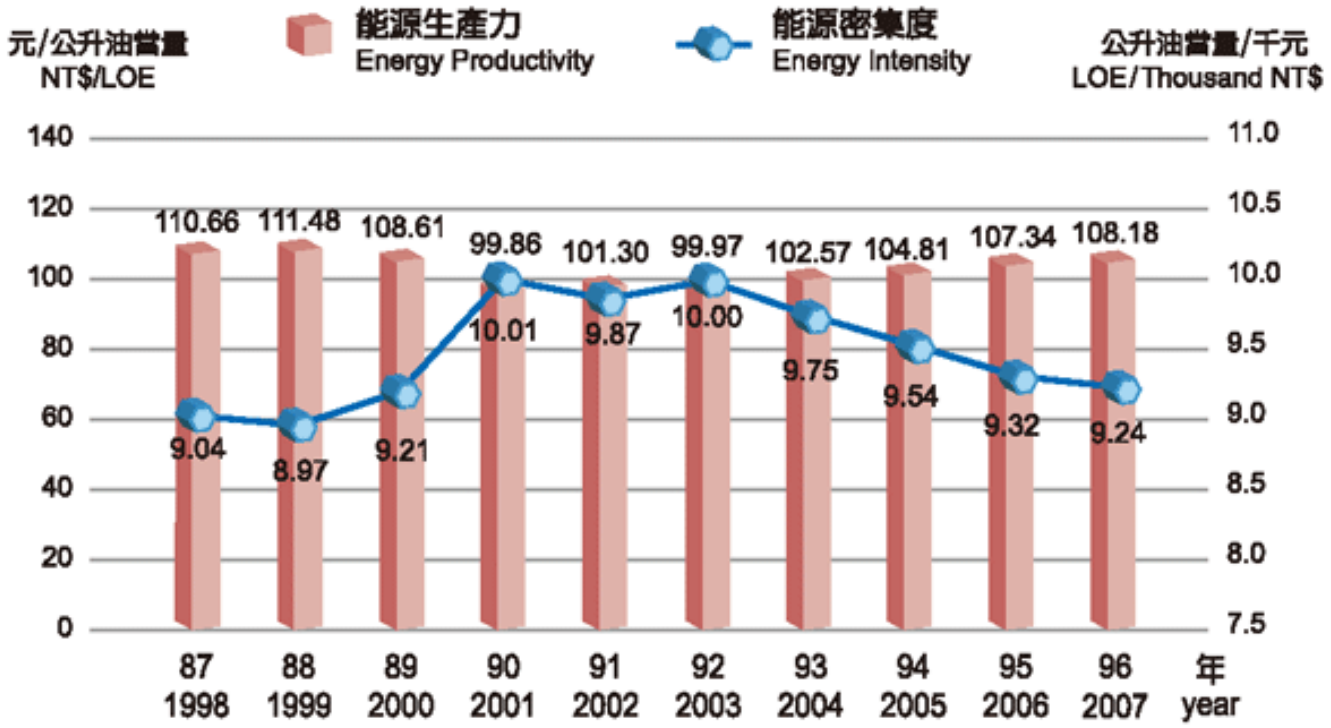


4. 歷年能源供給表（按自產與進口別）(2)
Energy Supply (by Indigenous and Imported) (2)

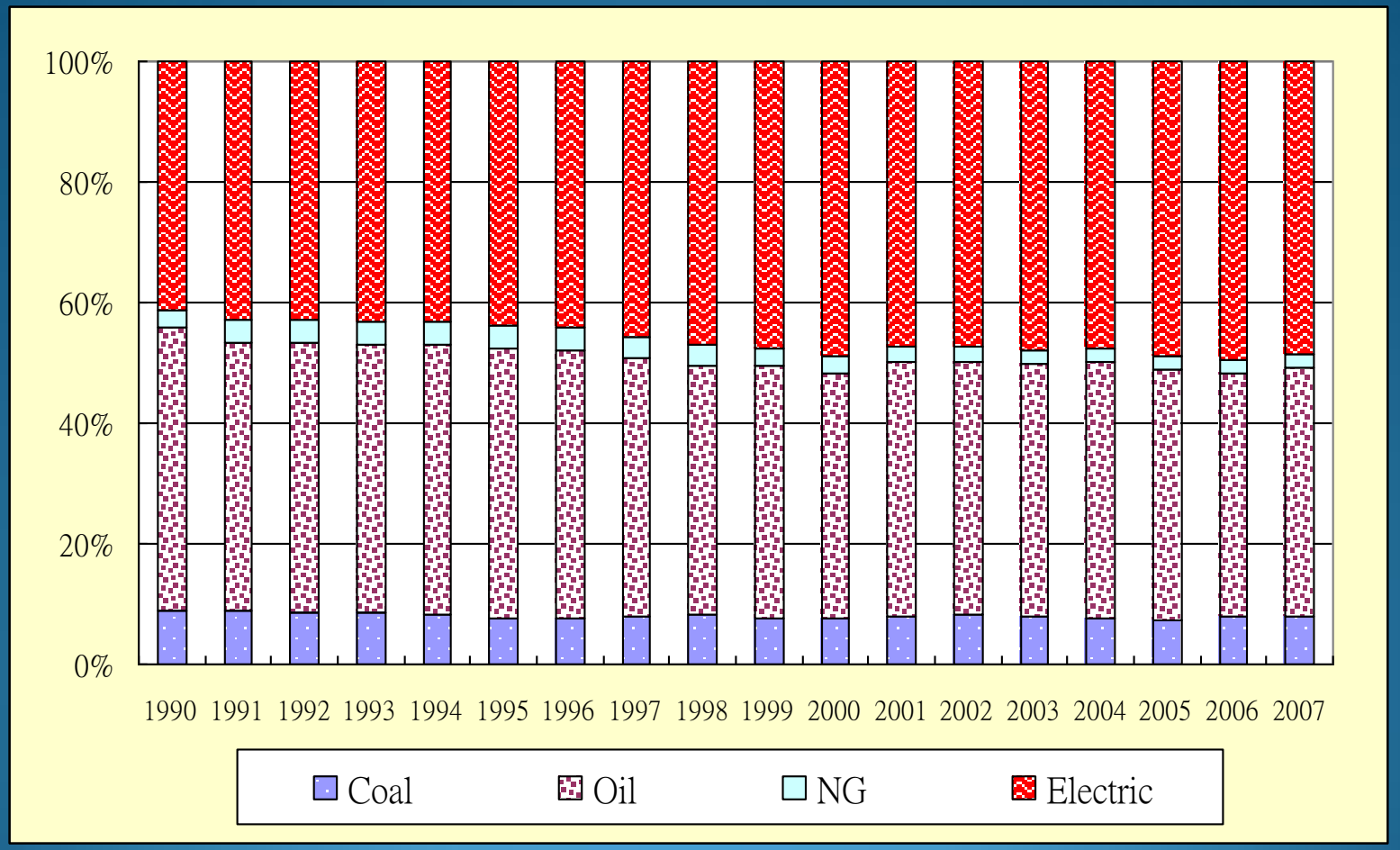
單位：%
Unit : %

年別 Year	自產 Indigenous							進口 Imported				
	合計 Total	煤炭 Coal	原油 Crude Oil	天然氣 Natural Gas	慣常水力發電 Conven-tional Hydro Power	太陽光電及風力發電 Solar Photovoltaic & Wind Power	太陽熱能 Solar Thermal	合計 Total	煤炭 Coal	石油 Petro-leum	液化天然氣 LNG	核能發電 Nuclear Power
1986	6.37	2.24	0.32	2.65	1.14	0.01	0.01	93.63	22.35	50.47	-	20.81
1987	5.50	1.63	0.27	2.70	0.87	0.01	0.02	94.50	24.86	52.45	-	17.19
1988	4.85	1.02	0.25	2.66	0.88	0.01	0.03	95.15	23.78	55.87	-	15.5
1989	4.17	0.56	0.31	2.23	1.04	0.00	0.03	95.83	23.38	54.60	1.61	16.24
1990	2.97	0.47	0.19	1.65	0.62	0.00	0.04	97.03	23.15	52.80	3.84	17.24
1991	2.81	0.36	0.11	1.32	0.97	0.00	0.05	97.19	25.45	52.82	3.70	15.22
1992	2.22	0.33	0.09	1.18	0.57	0.00	0.05	97.77	27.24	52.43	3.70	14.4
1993	2.32	0.27	0.09	1.23	0.67	0.00	0.06	97.68	27.15	52.27	4.39	13.87
1994	2.10	0.20	0.08	1.17	0.58	-	0.07	97.90	26.72	53.73	4.59	12.86
1995	1.87	0.12	0.07	1.07	0.54	-	0.07	98.13	27.32	53.23	4.51	13.07
1996	1.74	0.08	0.06	0.96	0.57	-	0.07	98.26	30.12	51.05	5.23	11.86
1997	1.77	0.06	0.06	0.94	0.64	-	0.07	98.23	29.43	51.18	6.08	11.54
1998	1.52	0.06	0.05	0.85	0.49	-	0.07	98.48	30.22	51.26	5.80	11.2
1999	1.28	0.06	0.04	0.70	0.41	0.00	0.07	98.72	31.33	50.77	6.05	10.57
2000	1.33	-	0.04	0.77	0.45	0.00	0.07	98.67	32.73	50.21	6.28	9.45
2001	1.10	-	0.05	0.77	0.21	0.00	0.07	98.90	33.10	49.00	6.75	10.05
2002	1.02	-	0.04	0.67	0.24	0.00	0.07	98.98	32.57	50.59	6.59	9.23
2003	0.90	-	0.03	0.57	0.23	0.00	0.07	[illegible]	32.41	50.89	7.33	8.47
2004	0.78	-	0.02	0.40	0.28	0.01	0.07	99.22	31.97	51.18	7.57	8.5
2005	0.72	-	0.02	0.33	0.28	0.02	0.07	99.28	32.31	50.68	8.01	8.28
2006	0.68	-	0.01	0.28	0.29	0.03	0.07	99.32	32.11	51.13	8.11	7.97

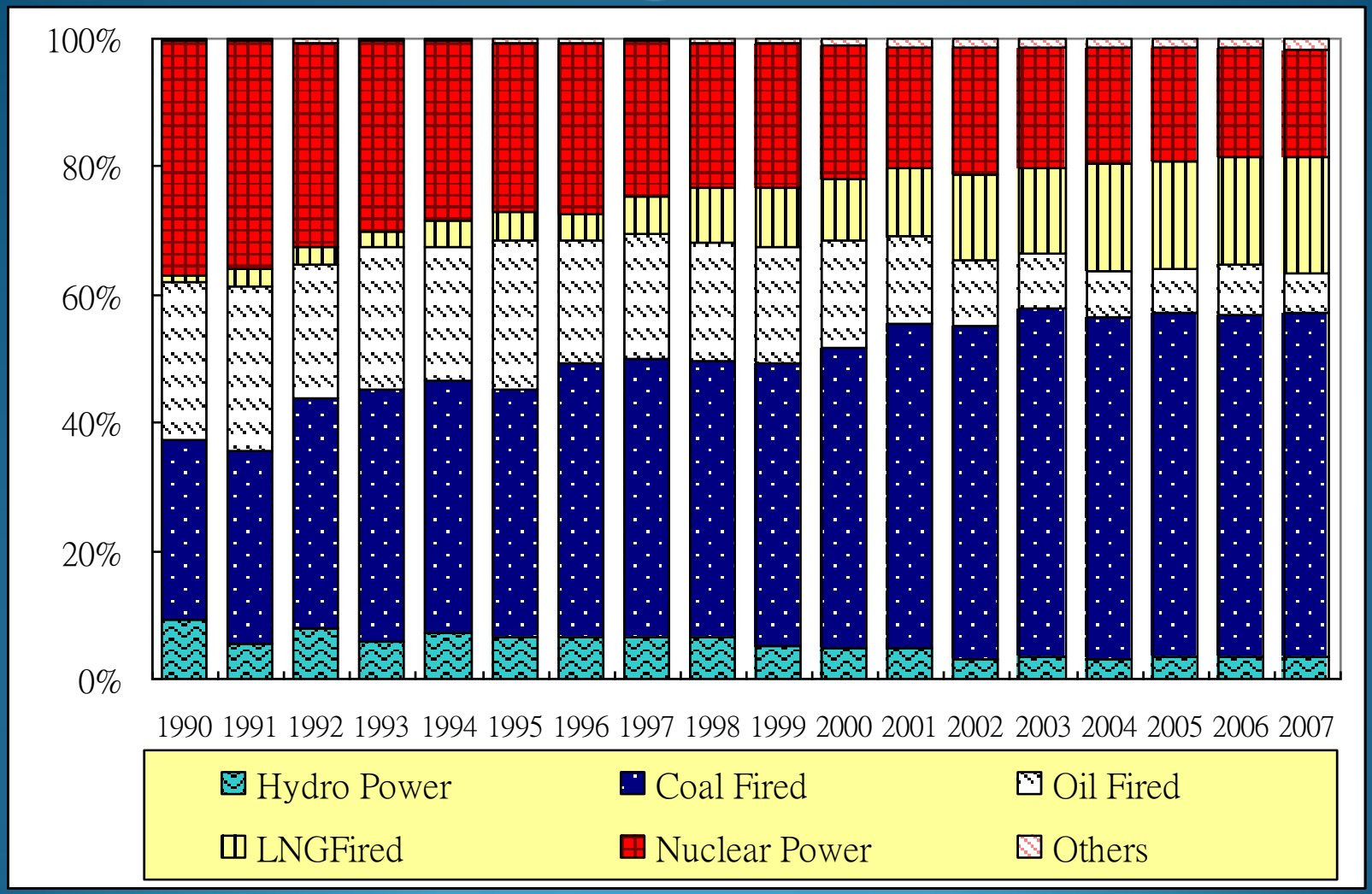
能源生產力與密集度
Energy Productivity and Energy Intensity



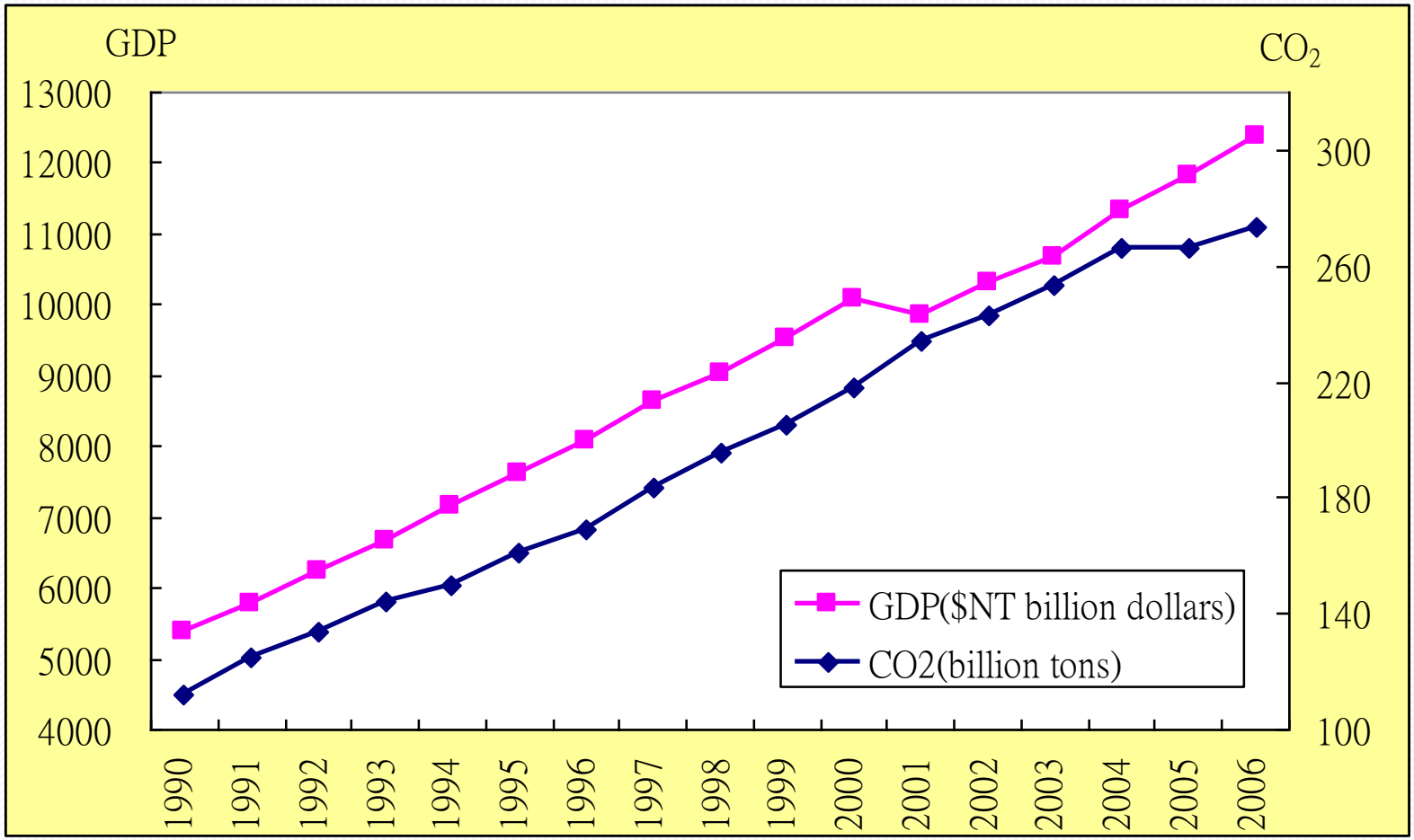
Energy Demand Structure



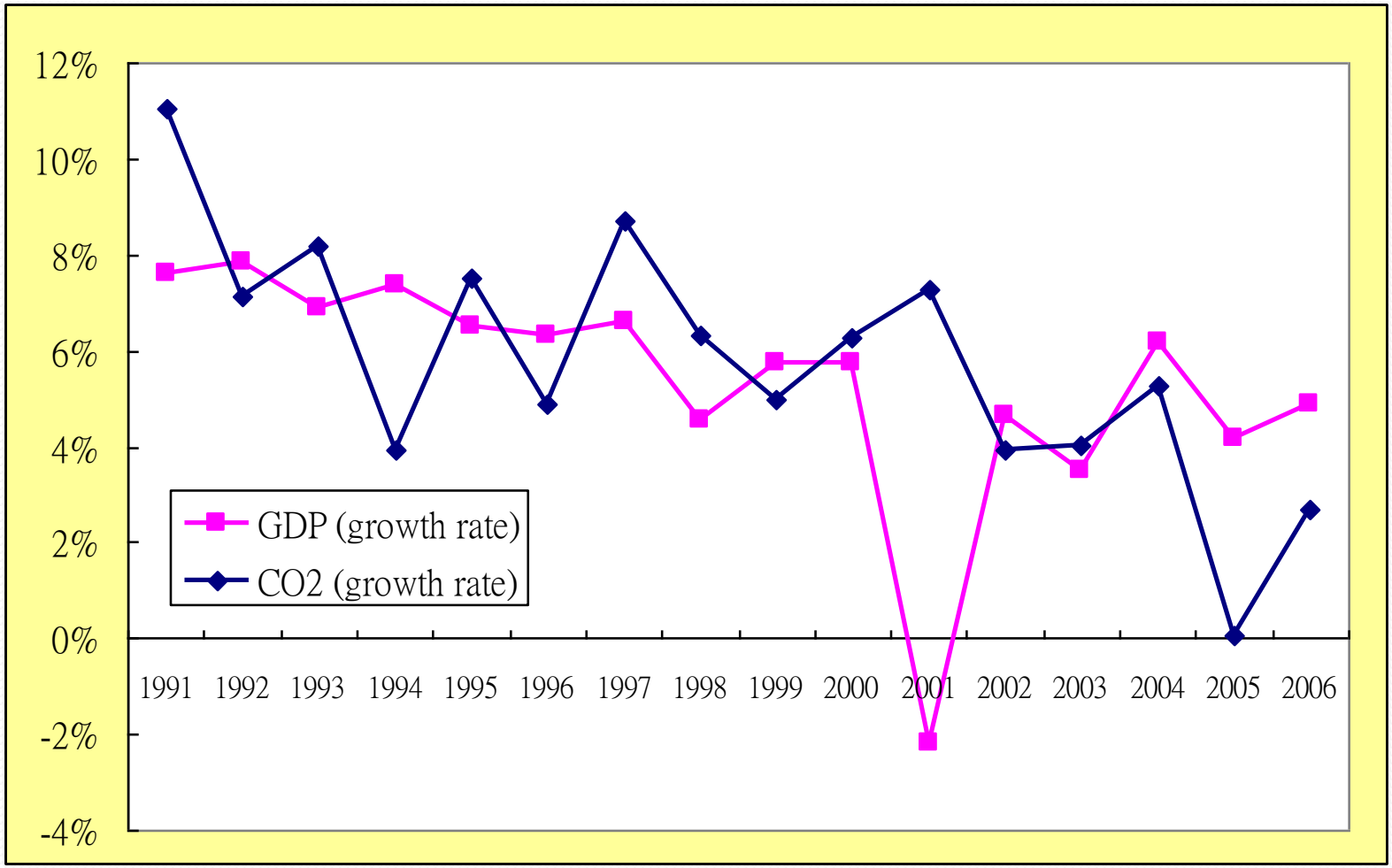
Electricity Structure



CO_2 Emissions and Real GDP

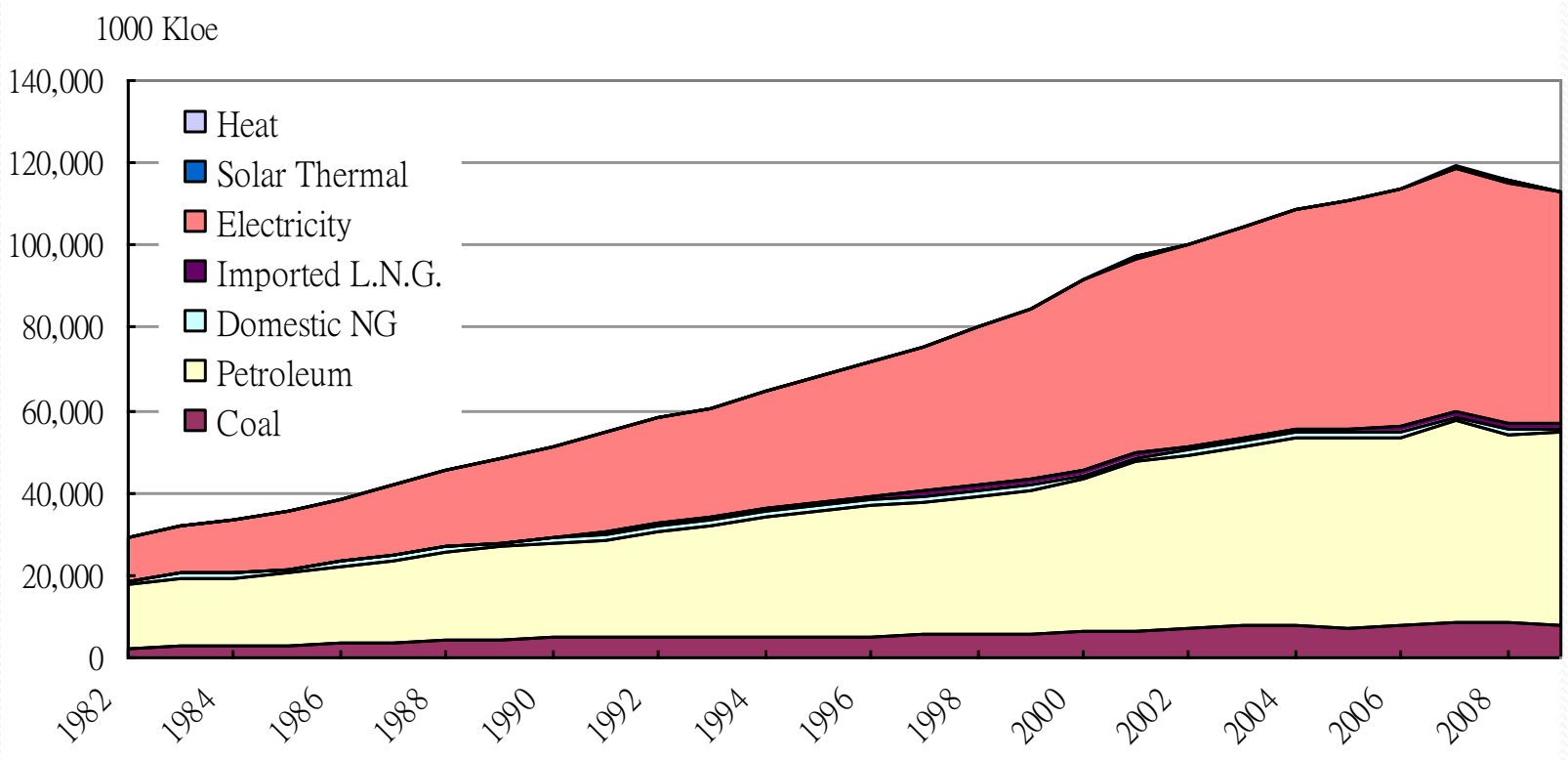


Growth Rates of CO_2 and RGDP



New and Renewable Energy Development in Taiwan

Energy demand by energy form (1982-2009)



Targets of renewable energy promotion in Taiwan

	2007		2010		2025	
	Installed Capacity (MW)	Ratio (%)	Installed Capacity (MW)	Ratio (%)	Installed Capacity (MW)	Ratio (%)
1. Hydropower	1922	5.0	2168	5.7	2500	4.4
2. Wind power	281.6	0.7	980	2.6	3000	5.3
3. Solar Photovoltaic	2.1	0.0	31	0.1	1000	1.8
4. Geothermal	—	—	—	—	150	0.3
5. Biomass	637	1.7	741	1.9	1400	2.5
6. Fuel Cell	—	—	—	—	200	0.4
7. Marine Current	—	—	—	—	200	0.4
Total	2843	7.5	3920	10.3	8450	15.1

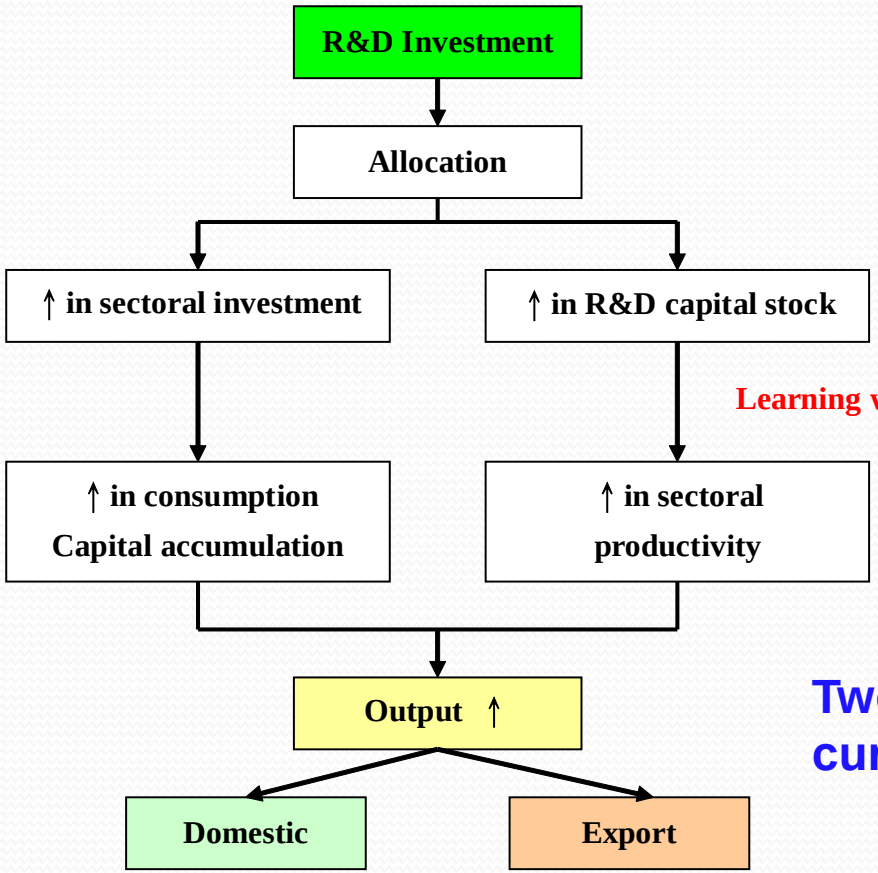
Installed Capacity in Taiwan (2009)

Item	Installed Capacity (MW)	(%)	Growth Rate (%)
Pumped Storage Hydro	**2,602.0**	**6.5**	**0.0**
Thermal	**30,194.3**	**75.0**	**5.2**
Taipower	22,487.2	55.9	4.7
IPP	7,707.1	19.1	6.8
Nuclear	**5,144.0**	**12.8**	**0.0**
Renewable	**2306.8**	**5.7**	**5.6**
Conv. Hydro			
Taipower	1,647.8	4.1	-0.1
IPP	39.1	0.1	0.0
Hydro Entrusted to Taipower	250.0	0.6	0.0
Wind Power			
Taipower	179.8	0.4	36.4
IPP	190.1	0.5	66.5
Total Installed Capacity	**40,247.0**	**100.0**	**4.2**

Energy Production in Taiwan (2009)

Item	Energy Production & Purchased (billion KWh)	(%)	Growth Rate (%)
Pumped Storage Hydro	3.3	1.7	-4.9
Thermal	145.8	75.3	-4.5
Taipower	96.8	50.0	-10.5
IPP	37.7	19.5	8.6
Cogen	11.3	5.8	15.6
Nuclear	40.0	20.7	1.8
Renewable	4.6	2.4	-6.3
Conv. Hydro			
Taipower	3.0	1.5	-13.3
IPP	0.1	0.1	2.3
Hydro Entrusted to Taipower	0.6	0.3	-14.2
Wind Power & Photovoltaic			
Taipower	0.4	0.2	36.3
IPP	0.5	0.2	44.7
Total Production	193.6	100.0	-3.3

Renewable R&D Investment and the Economy



Two-factor learning curve. ε= -0.3

The Integrated Modeling Approach

Buttom-Up and Top-Down Models of Taiwan

The Taiwan MARKAL Model

- The MARKAL model has a long history in Taiwan since 1990 (ITRI supported by BOE)
- The Institute of Nuclear Research (INER), Taiwan devoted to MARKAL development in 2005 to support the impact analysis of new and renewable energy technology development
- CYCU joined in 2006 to develop MARKAL-MACRO to enhance the macro analysis

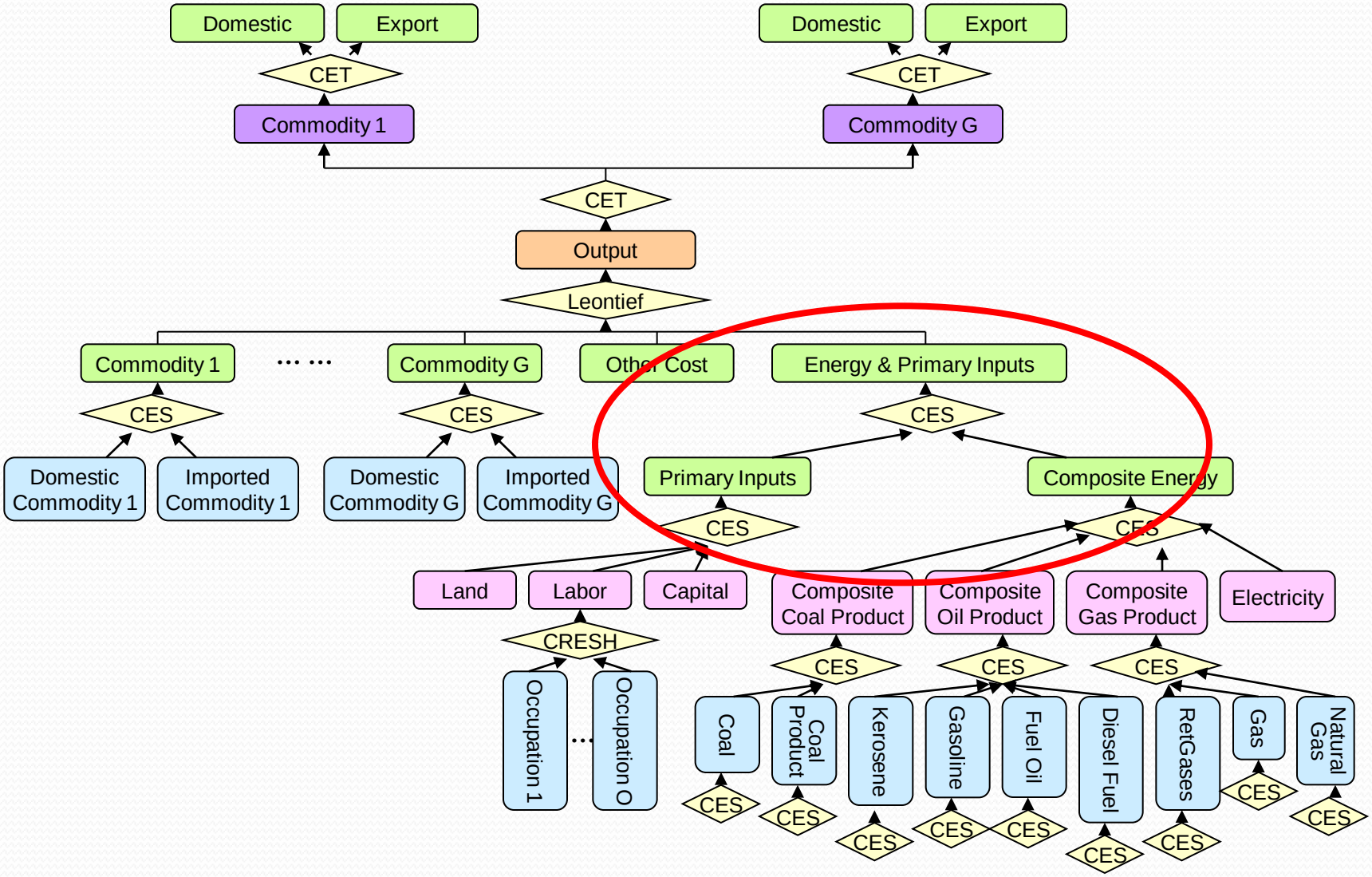
Features of Taiwan MARKAL developed by INER

- Benchmarking in 2000
- Updated energy technology data
- Enhanced electricity technology data
- New and renewable energy
- 30 energy demand services
- Currently solved up to 2050

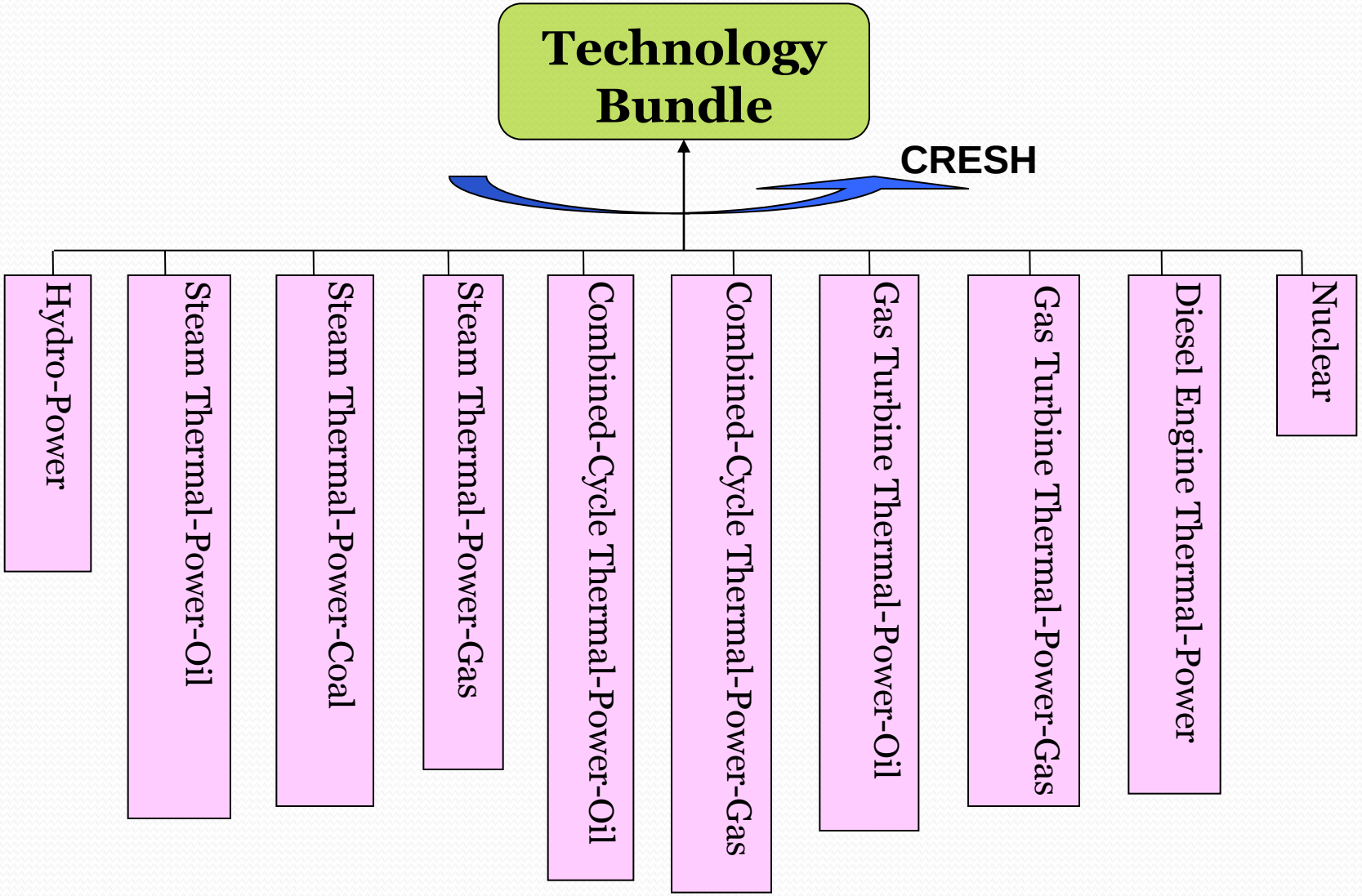
GEMEET – Dynamic CGE

- *G*eneral *E*quilibrium *M*odel for *E*nergy, *E*conomic and *T*echnology Analysis
- Recursively dynamic + Technology learning
- 81 sectors
- New and renewable energy sectors
- Different electricity generation technologies
  - Traditional + PV, Wind, IGCC
- Solves up to 2050 with GEMPACK

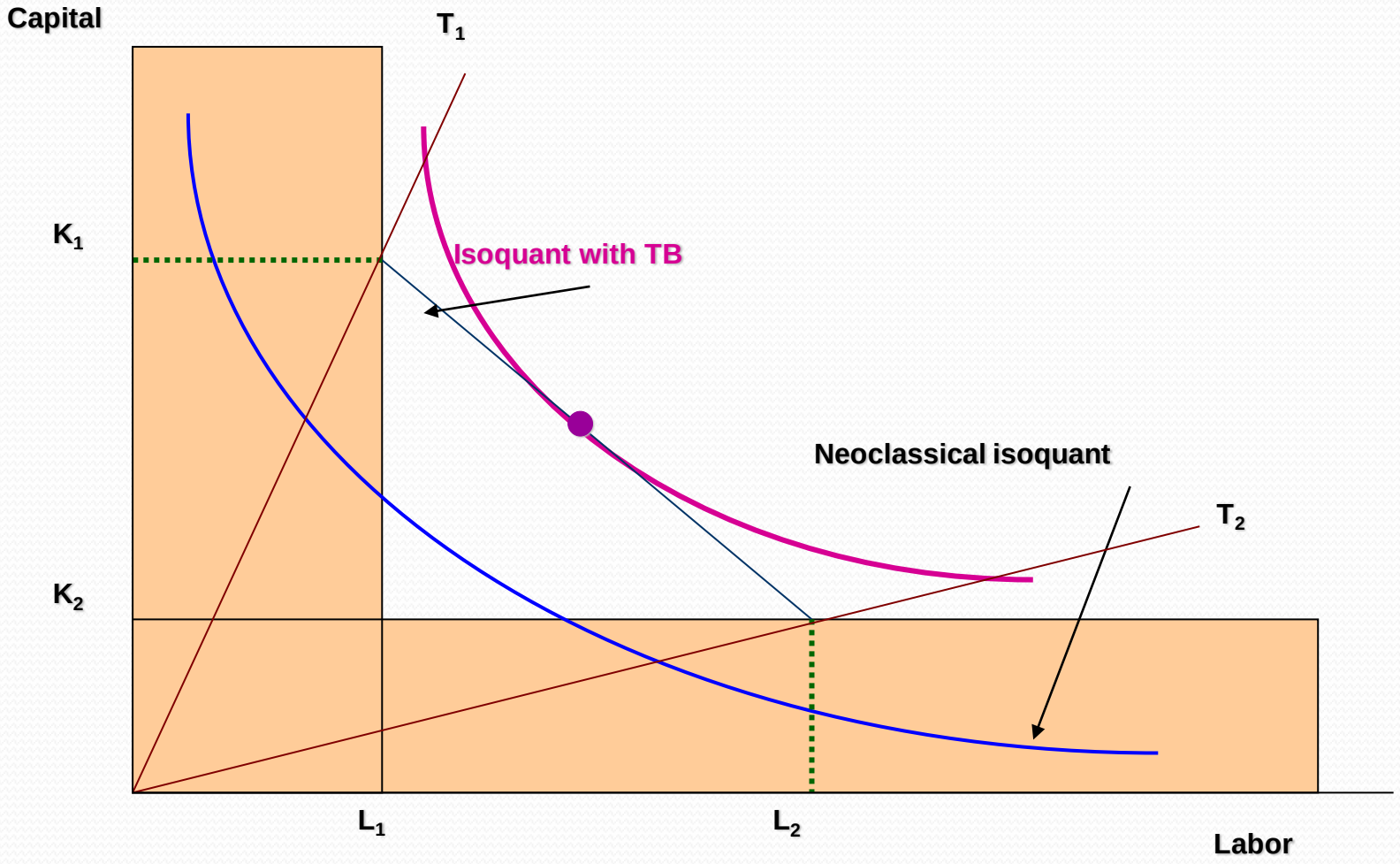
Nested structure



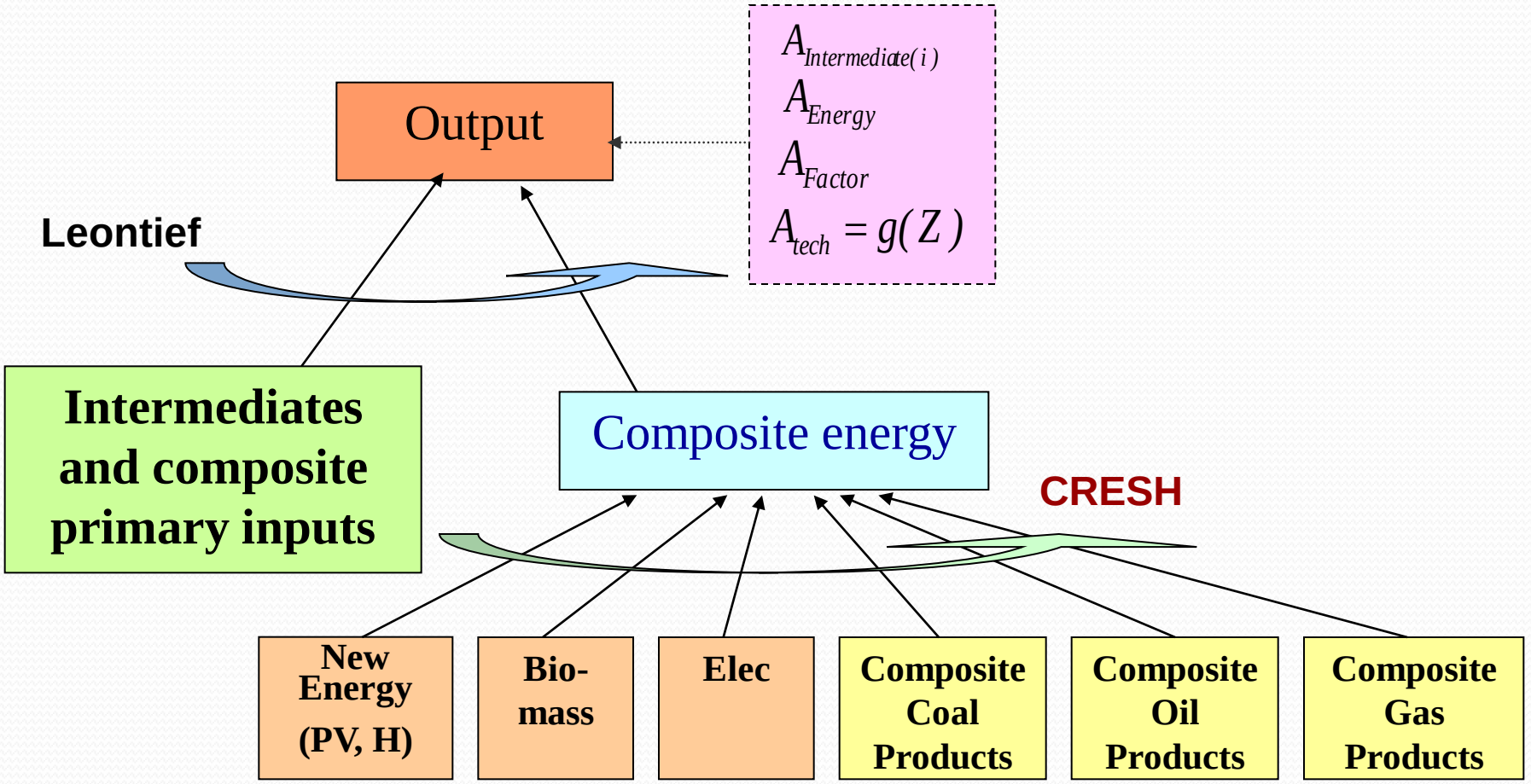
Nested Structure of Electricity Sector



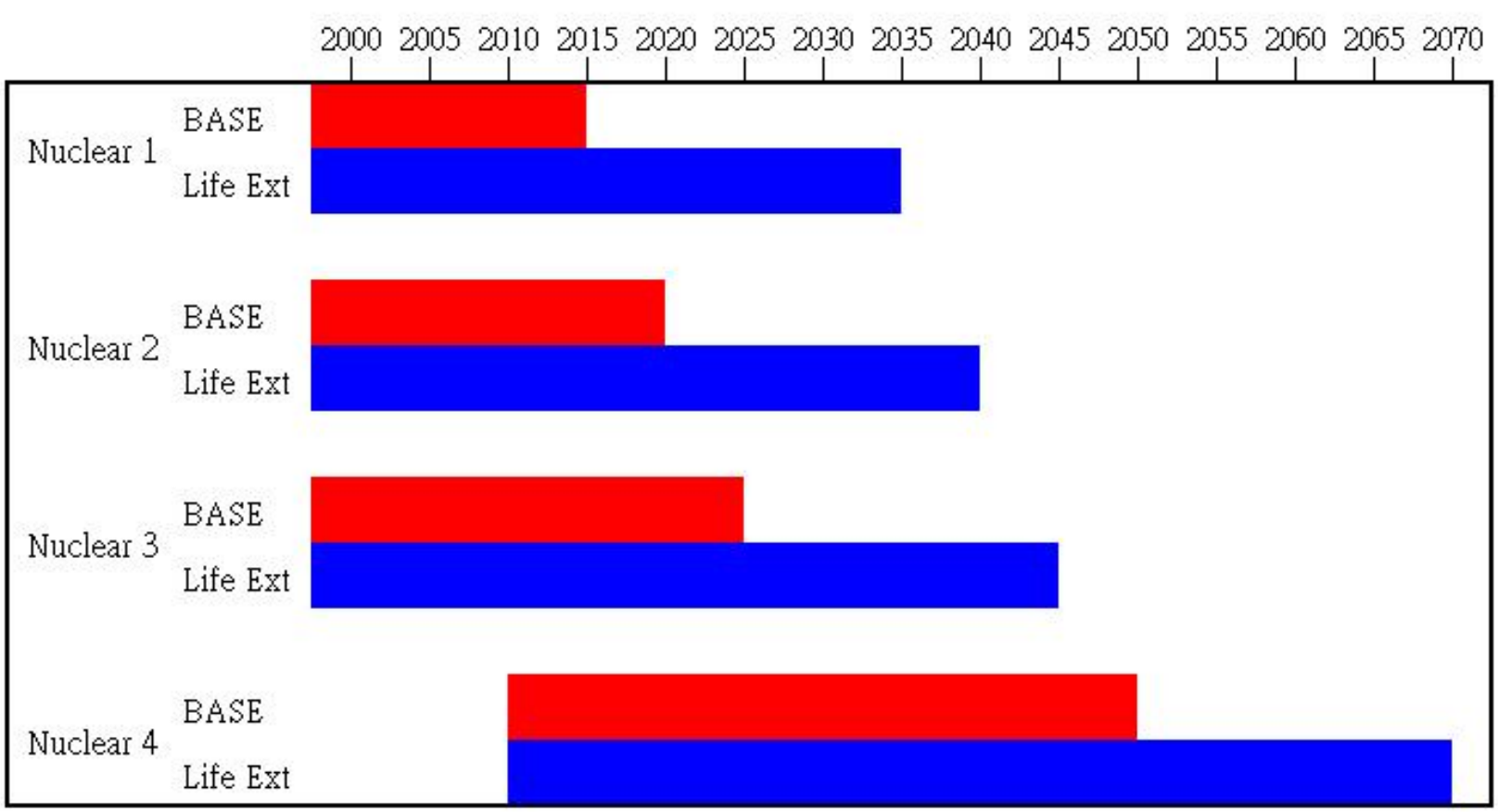
Technology Choices



Endogenized Technological Change



Nuclear Power Plans & Extensions



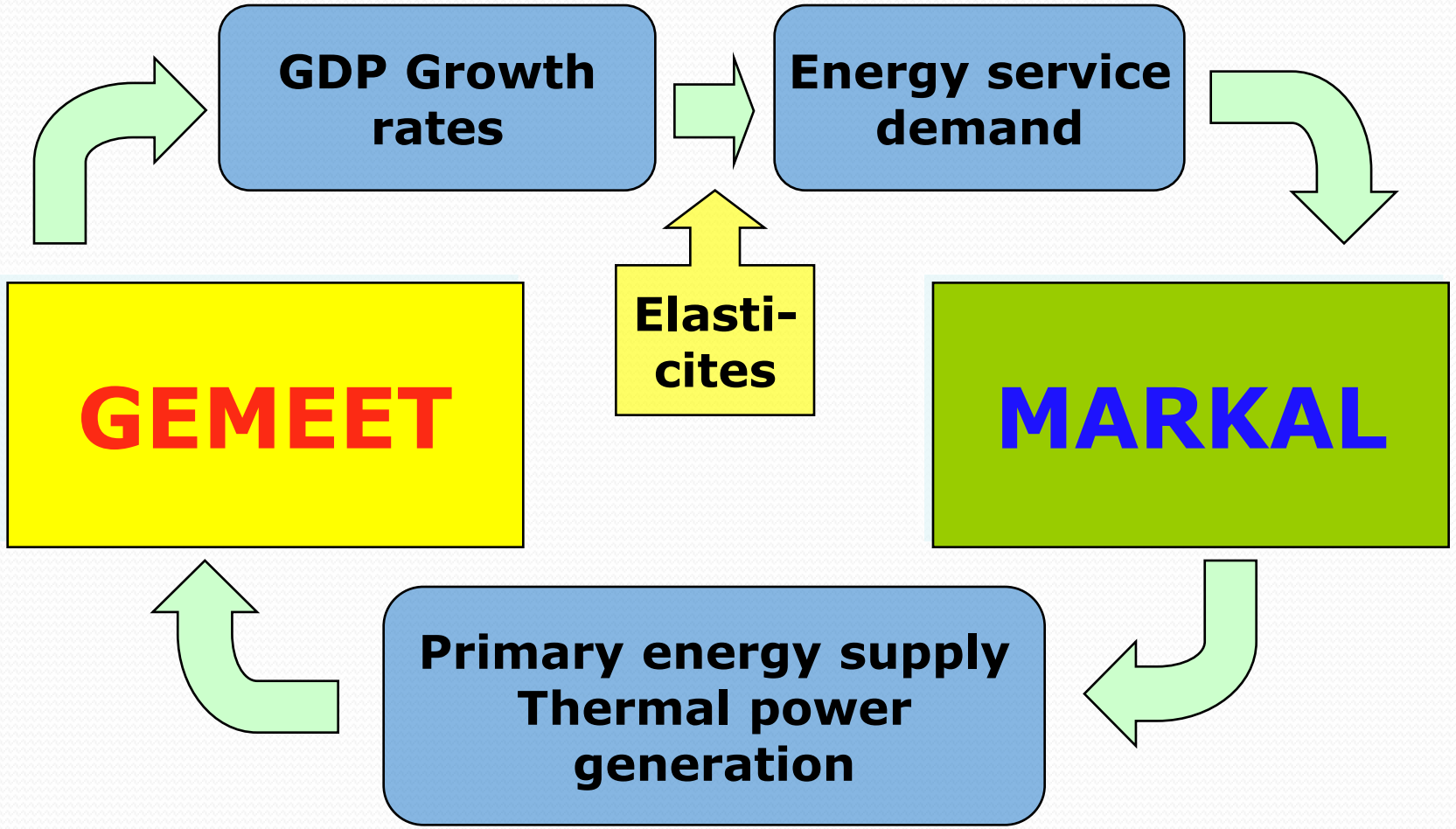
Integrated Model Analysis

Linking Buttom-Up and Top-Down Models

Linking Strategy

- **Policy issue to be explored**
  - **Determine the linking variable or parameter**
- **Benchmark integration**
  - **Examine some variables or Indicators**
  - **Examine individual variables or indicators**
- **Policy shock integration**
  - **Shock both models or just one of them?**

Integration of GEMEET and MARKAL



Sectors of GEMEET

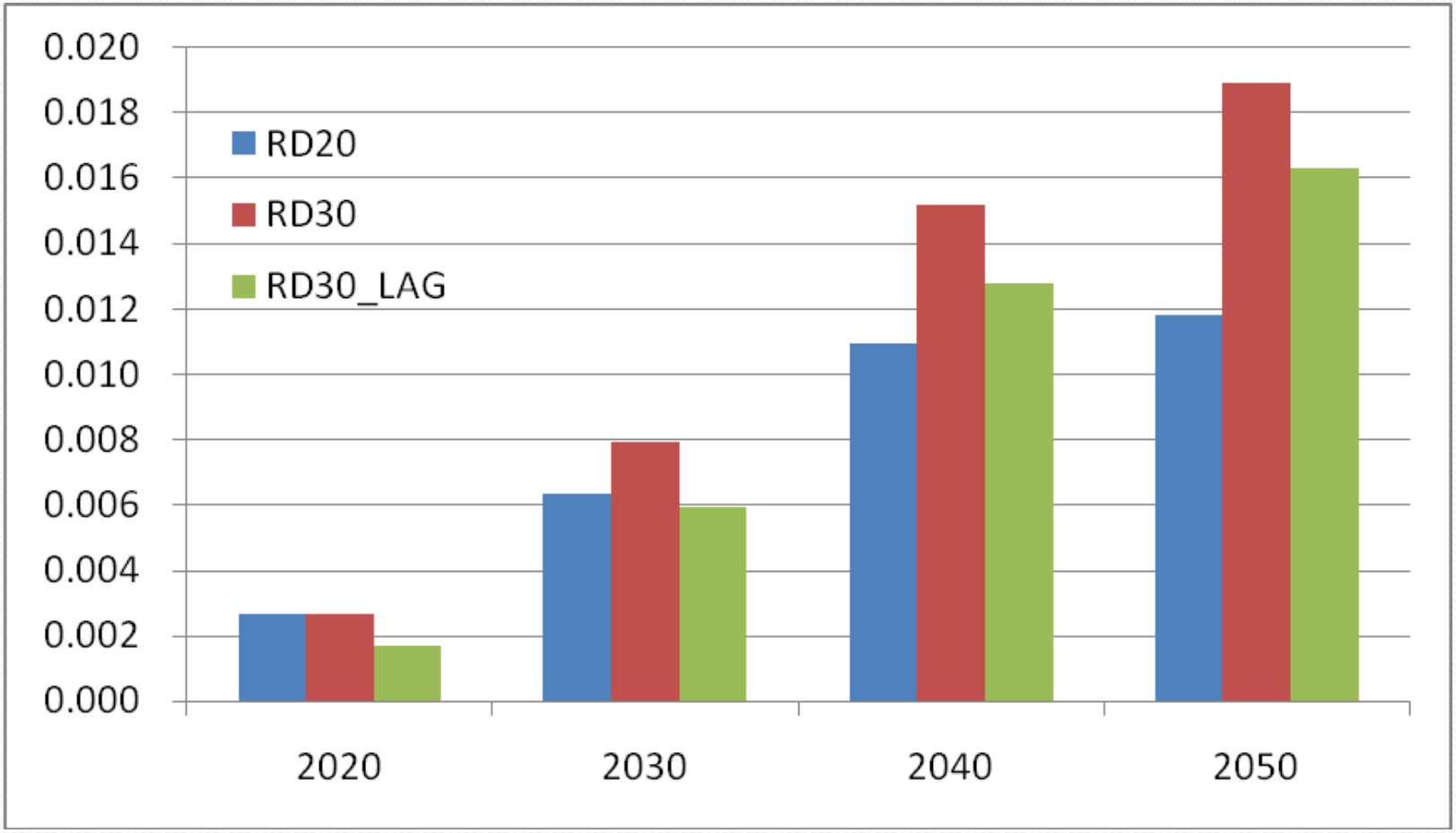
1	Paddy	21	MisChemical	41	PhotoVoltaic	61	HydroElec
2	Livestock	22	Gasoline	42	HCPV	62	PVElec
3	Forestry	23	DieselFuel	43	BioDiesel	63	HCPVElec
4	Fisheries	24	AviatFuel	44	BioEthanol	64	WinPwrElec
5	Crude_oil	25	FuelOils	45	EthGasoline	65	SIGCCElec
6	Natural_Gas	26	Kerosene	46	BioEth_Equip	66	CoGenElec
7	Coal_Prods	27	Lubricants	47	PV_Equip	67	Gas
8	Other_Min	28	Naphtha	48	HCPV_Equip	68	Water
9	ProcFood	29	RetGases	49	WinPwr_Equip	69	Transport
10	Beverage	30	Asphalt	50	SIGCC_Equip	70	CommServ
11	Tobacco	31	PetroRefiNEC	51	Elec_NEC	71	Wholesale
12	Textile	32	NonMetalic	52	TransEquip	72	Finance
13	Apparel	33	SteelIron	53	MiscProd	73	Realestate
14	Leather	34	MiscMetal	54	HouseConst	74	EatingHotel
15	WoodBamboo	35	Metallic	55	PublicConst	75	InforServ
16	Paper	36	Machinery	56	EndUseElec	76	BusServNEC
17	Chemical	37	HouseElec	57	Thermal_Oil	77	PublicServ
18	Fiber	38	DataProcEq	58	Thermal_Gas	78	EduTrnServ
19	Plastic	39	CommunEqip	59	Thermal_Coal	79	MedHelServ
20	PlasticPrd	40	Electronic	60	NuclearElec	80	Recreation
						81	Undistribt

Results and Analysis

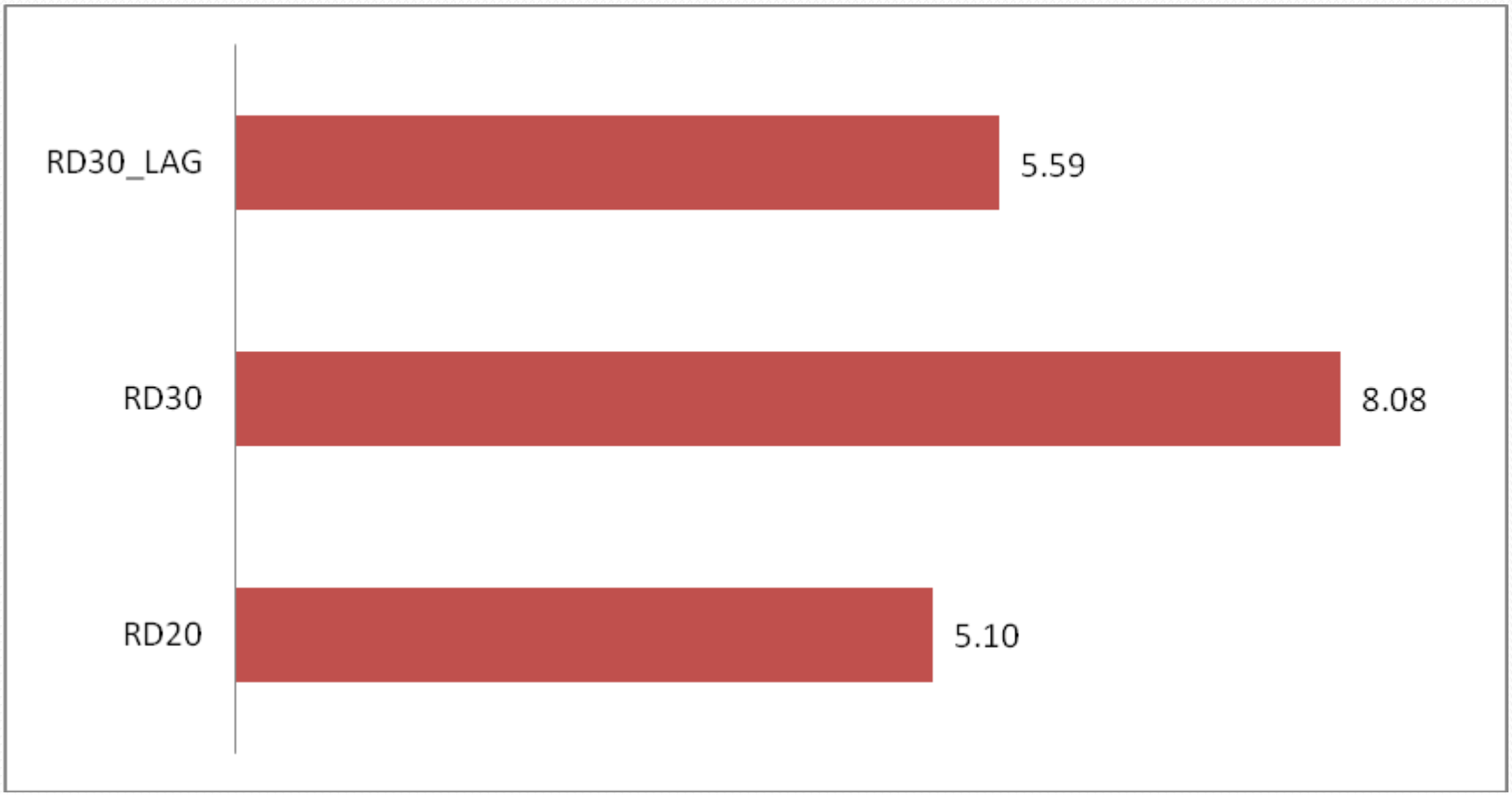
Scenarios

- **RD20 – Government invests a total of 60 billion NT$ between 2010 and 2020 for renewable energy technology development.**
- **RD30 -- Government invests a total of 220 billion NT$ between 2010 and 2030 for renewable energy technology development.**
- **RD30_LAG – Same as RD30, but the effect of R&D investment on productivity growth will take effect three years after the investment**
- **All with a crowding out of other government expenditures.**

Real GDP change rate (relative to baseline)

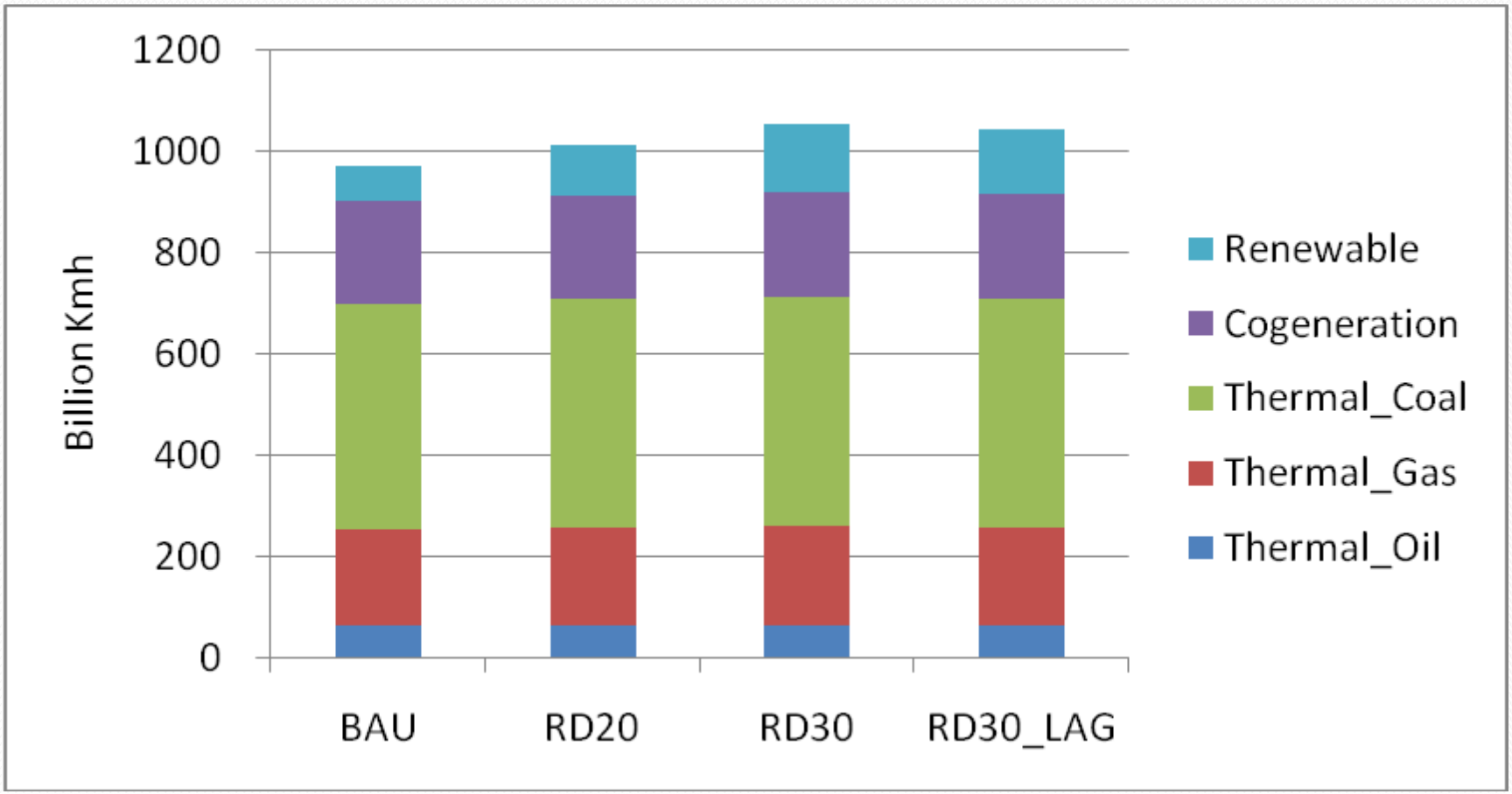


Investment multiplier under different scenarios

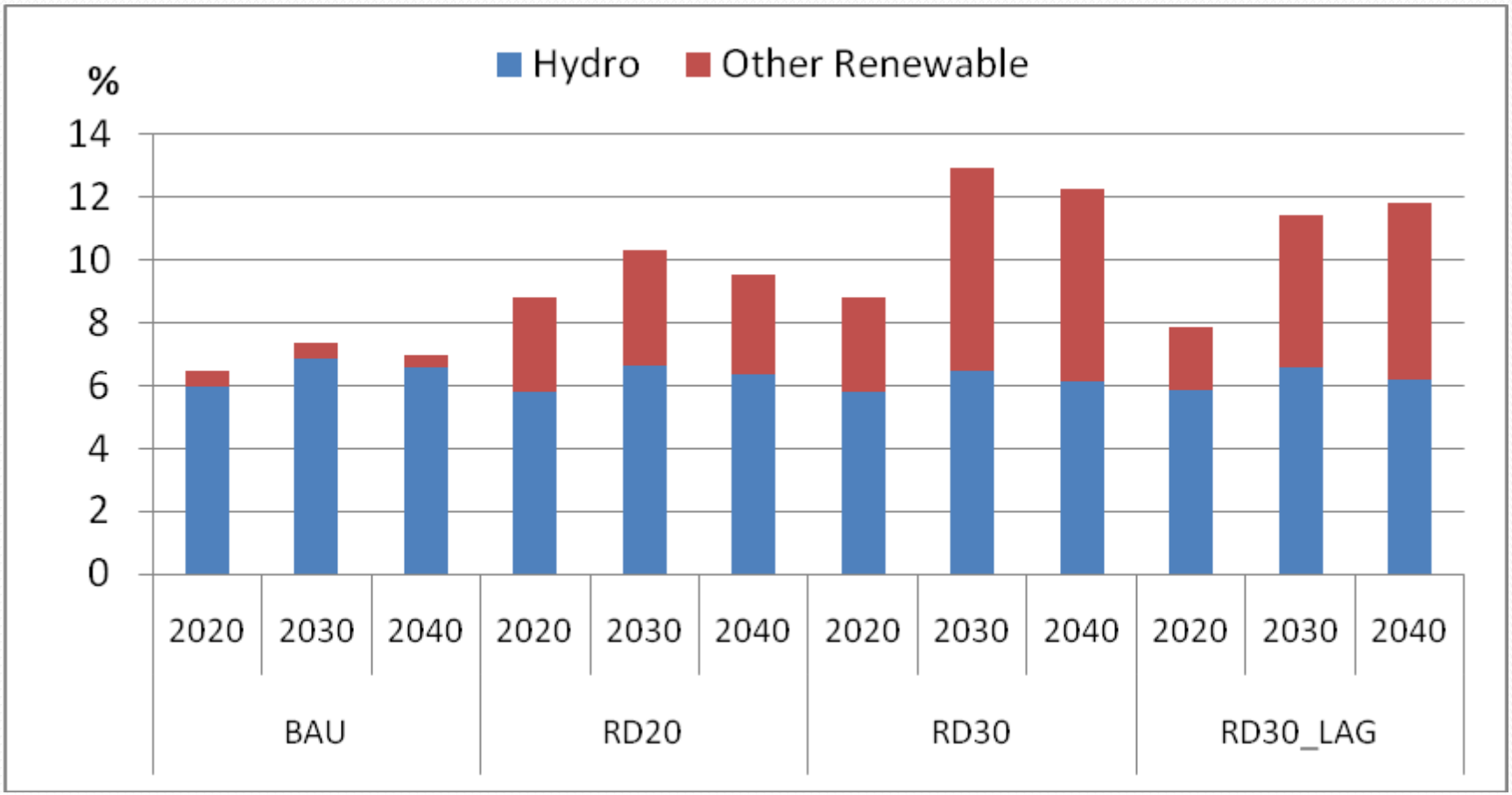


CO_2 emission change rate (relative to baseline)

Changes in power generation mix



Share of renewable in power generation for selected years



Conclusions

- **Analysis results indicate that with a reasonable level of R&D investment and technology learning process, new and renewable energy technology development is cost-effective and shall have positive environmental benefit. However, the environmental benefit of R&D in renewables might not be so significant, which suggests that renewable energy may not be the sole solution to CO_2 emission reduction. Other measures or incentives are required to support a designated reduction scheme.**

Thank you for your attention!