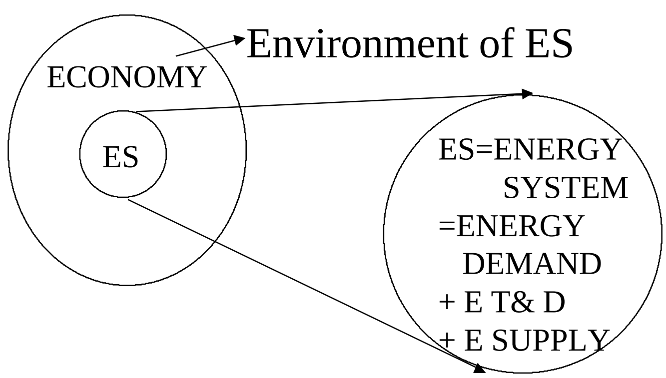
ENERGY PLANNING MODELS

BY

AMULYA KUMAR N. REDDY

ENERGY SYSTEM



ENERGY SYSTEM-ECONOMY INTERACTIONS

Energy is a

- Factor of industry & agricultural production.
- component of household consumption

• Therefore, energy is crucial for intermediate production & for final consumption

ED/unit of intermediate production
ED/unit of services for HH needs = f(EU Tech)

Choice of EU Tech = f(Economic factors)

Economic factors:capital costs, carrier prices, etc.

ES Supply - Demand Balances

Sources → Fuel Cycle → Sevices

PE → SE → FE → UE

loss loss loss

ES-Economy Interactions

\+ Complex

ES Supply - Demand Balances

Models → response to complexity

MODELLING

Models are

- path to understanding in the face of complexity
- simplified representations of reality
- physical constructions
- mathematical equations
- geometrical diagrams
- framework for conceptualization
- tool for anaysis
- scheme for (i)clarifying past, (ii) understanding present and (iii) visualizing future

---

Energy Future = Future ED + Future E supply

ES Past → ES Present → Future ED

↓

Future E Supply

ESTIMATION OF FUTURE ED

1. Trend or BAU Method

Present ED → Future ED → Future E Supply

Trend

(a) Single-sector method

Time-series data → curve fitting → Future ED

(b) Multi-sectoral trend

ESTIMATION OF FUTURE ED (CONTD).

Present ED (Base) —— $FED = PED\,(1+g)^t$ ——→ Future ED

Growth Rate g

(a) Single Sector (b) Multi-sector

Eg: LRPPP Projection for 1999-2000 for Karnataka Electricity Demand

$15{,}500$ GWh/year x $(1+9\%)^{13}$ = $47{,}500$ GWh/year

(15,500 ↓ 1986-87; 47,500 ↓ 1999-2000)

ES-Economy Relationship → DIALECTICAL

Each implies other

Each transforms other

(a) Ignore dialectical relationship

Economic activity EXOGENOUS

Economic activity → Future ED →

HIERARCHICAL OPEN-LOOP MODELS

(b) Include dialectical relationship

Economic activity ENDOGENOUS

Economic activity ⇄ Future ED

GLOBAL CLOSED-LOOP MODELS

ENERGY DEMAND - SOME GENERAL CONSIDERATIONS

Society → Many Activities

Each Activity → Energy Intensity (I_I)

Each Activity → Contribution to GDP(C_I)

$$\text{Energy Demand} = \sum_I C_I\, I_I$$

$$= \sum \alpha_I\,(\text{GDP})\, I_I$$

$$= (\sum \alpha_I I_I)\ \text{GDP}$$

If ($\sum \alpha_I I_I$) Remains constant, GDP , Energy

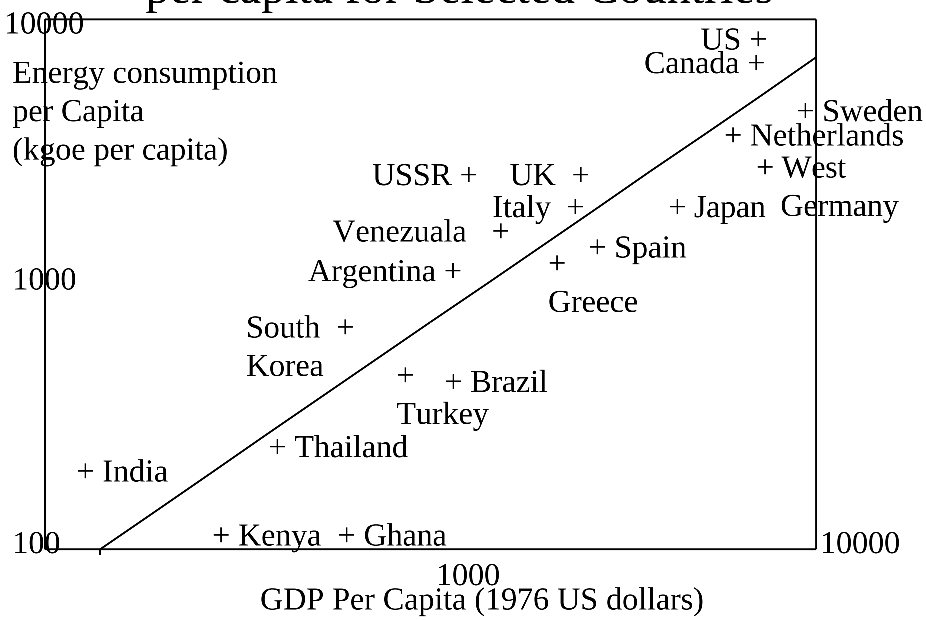
Therefore, Energy-GDP Correlation

Changes in Energy Demand
can arise from

Changes in Energy Intensity	Changes in contribution to GDP (CI), i.e., Changes in α_I
Technical Changes	Structural Changes
(1) Efficiency improvements	(1) New composition of Product Services, i.e., New α_I's
(2) Process Changes	
(3) Product Changes	

Result: $(\alpha_I I_I)$ & $S(\alpha_I I_I)$ can decrease and Decouple energy from GDP

GDP per Capita Vs Energy Consumption per capita for Selected Countries



CONVENTIONAL SUPPLY-BIASED PARADIGM

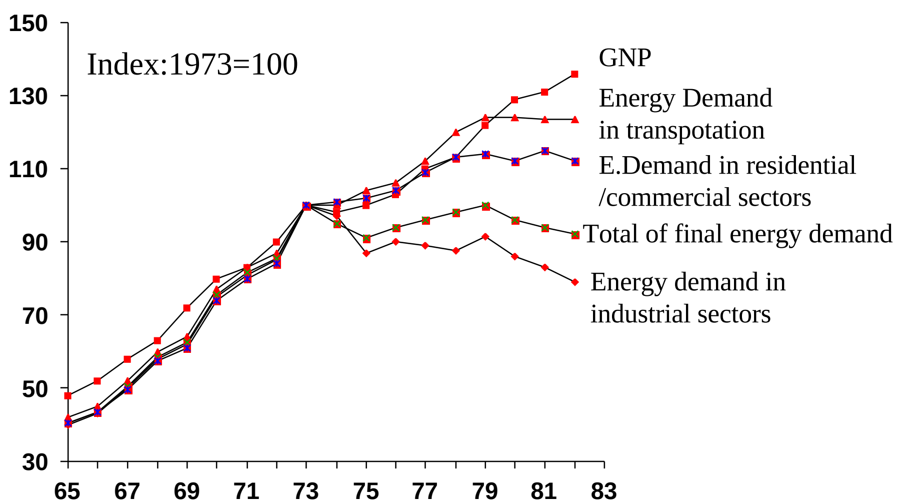
Development

Economic growth → Energy as an end → Demand Projection → Focus on suppy increase

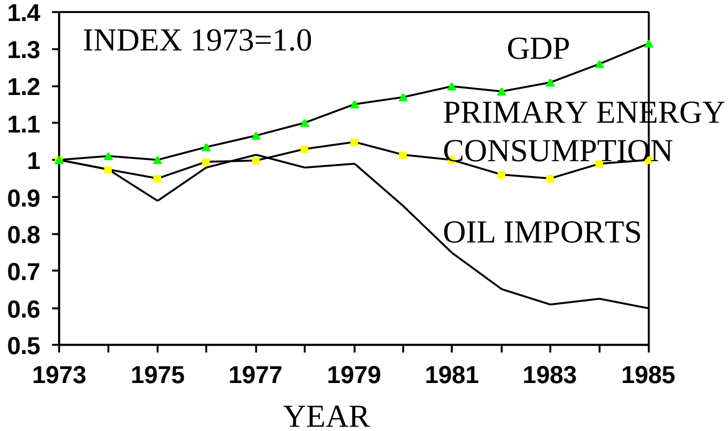
Ignore conservation. → Ignore environmental impacts → Ignore Renewables

Choose Source-mix

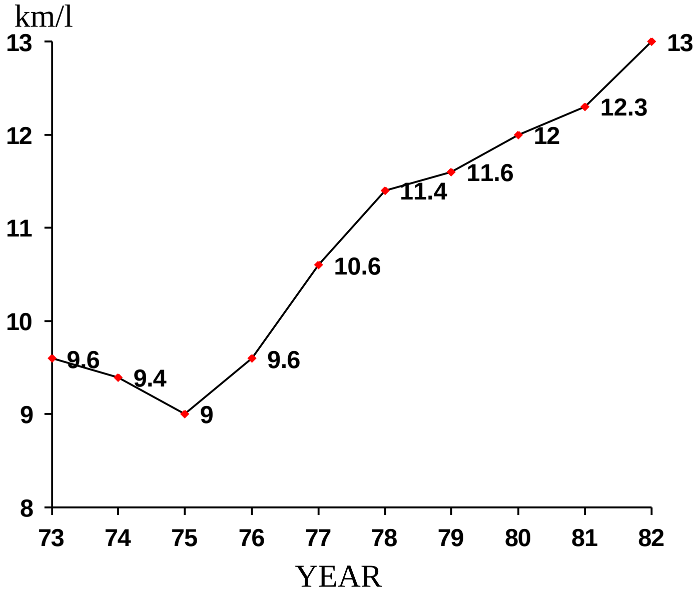
Trends in Japan's Energy Demand by sector and GNP



OECD COUNTRIES 1973-1985



CHANGES OF FUEL EFFICINCY OF JAPANESE PASSENGER'S CARS



INCORPORATION OF EFFICIENCY IMPROVEMENTS IN ESTIMATE OF FUTURE ED

(a) Implicit incorporation via energy prices

$ED = f(GDP, P)$

$= A.GDP^{a}.P^{-b}$

$\ln ED = \ln A + a \ln GDP - b \ln P$

$a = (\delta \ln ED / \delta \ln GDP)_{P}$ $-b = (\delta \ln ED / \delta \ln P)_{GDP}$

a is GDP Elasticity of ED

b is Price Elasticity of ED

ED, GDP and P are f (time) Therefore,

$\ln ED(t)/ED(0) = a \ln GDP(t)/GDP(0) - b \ln P(t)/P(0)$

But $ED(t) = ED(0)\,[1+g_{ED}]^{t}$ or $ED(t)/ED(0) = (1+g_{ED})^{t}$

and $\ln(1+g_{ED}) = g_{ED}$ $g_{ED} = a\, g_{GDP} - b\, g_{P}$

If $P(t) = P(0)$ i.e., $ED = A.GDPa$

$gED = a\, gGDP$ $a = d \ln ED / d \ln GDP$

$a = g_{ED}/g_{GDP}$, i.e., GDP eleasticity of ED= Ratio of growth rates of ED and GDP

$\Delta ED/yr = ED(1) - ED(0) = ED(0).\, g_{ED} = ED(0).a\, g_{EDP}$

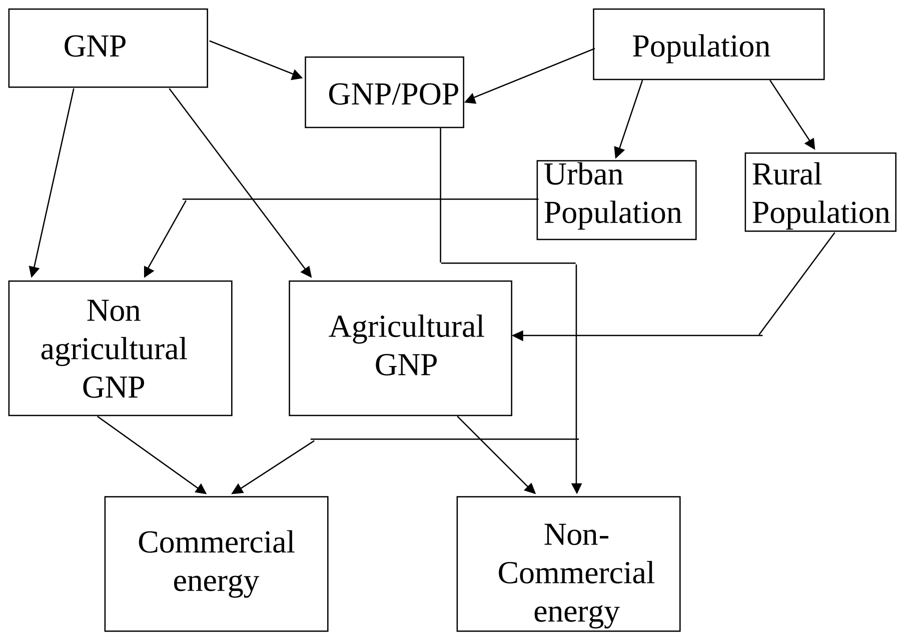
$\Delta I/yr = ED(0).g_{EDP}.a.UCOP$

= 600 GW x 4% x 1.5 x \$2777/kW

= \$100 billion/year

Annual Investment required for electricity sector
= E(0) * a * g_G * UCOP
= E(0) * g_E * UCOP
where UCOP = Unit cost of Power ($/kW)
WB calculation at 14th WEC:
E(0) = 600 GW, g_E = 0.06 (6%)
& UCOP = $2,777/kW, and therefore
Annual Investment required for electricity sector
= $100 billion/year
WB-type caculation for Karnataka:
E(0) = 2.25 GW, g_E = 0.06 (6%)
& UCOP = $2,777/kW, and therefore
Annual Investment required for electricity sector
= $422 million/year

Alternative Karnataka Scenario calculation:
E(0) = 2.53 GW, gE = 0.0354 (3.54%)
& UCOP = $1,600/kW), and therefore
Annual Investment required for electricity sector
= $143 million/year = 1/3 of WB approach
GoK VIII Plan
E(0) = 2.76 (1989) gE = 7.37%
& UCOP = $ 1851/kW and therefore
Annual Investment required for electricity sector
= $380 million/year



Simplified structure of the Parikh model

Explicit Incorporation of EI

(b) If c = rate of EI

then $ED = A.GDP^a/(1+c)^n$

$ED(t)/ED(0) = [GDP(t)/GDP(0)]^a/1/(1+c)^n$

$(1+g_{ED})\ (1+c) = (1+g_{GDP})^a = 1+a\ g_{GDP}$

$a_{eff} = g_{ED}/g_{GDP} = a_{FE}\ (c/g_{GDP})/1+c$

$a_{FE} = a\ (c = 0)$

DOUBLE ELASTICITY MODEL

$ED = A.\ GDP^a\ P^{-b}\ /\ (1+c)^n$

PROBLEMS WITH ELASTICITIES

- Price elasticities can’t cope with following problems:
  - How will future price increases affect ED and carrier substitution
  - What is the role of non-price-related measures
  - How will economy (e.g.recession) will affect ED
- Elasticities are difficult to measure and vary a great deal
- Price elasticities overemphasize role of prices

  Any change not explained by GDP is ascribed to price including non-price-related measures

PROBLEMS WITH ELASTICITIES

- Elasticities are black boxes that don’t explain how prices affect ED

e.g. Price elasticity of household demand will integrate effect of prices on
  - level of ED
  - changes in existing EU equipment
  - choice of new equipment

I/O: method of systematically quantifying the mutual relationship between various sectors of a complex economy

$$Xi = [X_{i1} + X_{i2} + ... + X_{ij}] + Y_i$$

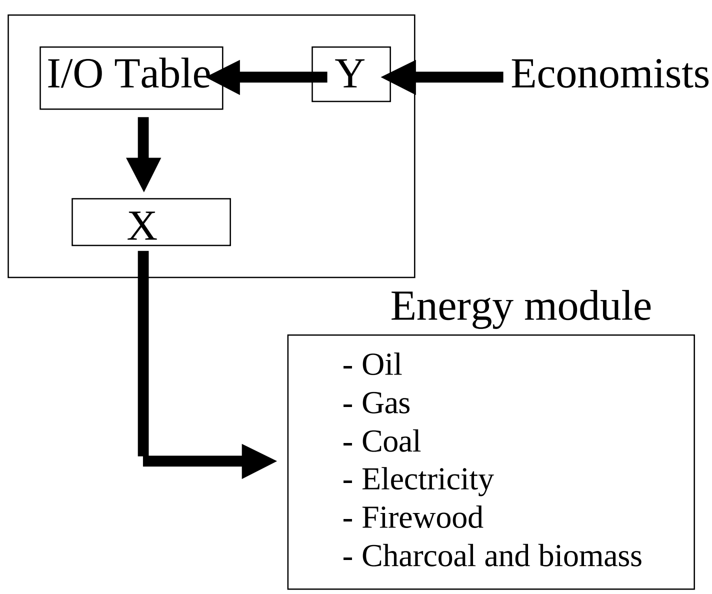
$$= \Sigma X_{ij} + Yi$$

$$= \quad A_{ij} X_i + Y_i$$

$$X = AX + Y$$

$$X = [I - A]^{-1} Y$$

ED = Z X , where Z = energy used in production



Structure of the MSEDM model

TECHNO-ECONOMIC MODELS

Σ End-uses ⟶ ΣUE ⟶ Σ FE ⟶ ED

End-use data ⟶ not always available

So, work with activities

Economy = Σ Sectors

= Σ Sectoral activity

Each sectoral activity

Activity level per capita   Specific energy (GJ/unit level)

$ED=\Sigma[(\text{Activity level})_i \times (\text{Specific energy})_i]$

A THOUGHT EXPERIMENT

$E_{total} = \Sigma(\text{Activity level})_i * (\text{Specific Energy})_i$

Assume:

Activity levels=Activity levels of Western Europe in 1970's

e.g. 320 kg steel per capita

[Specific Energy]cop to Most energy-efficient end use tech.
(commercial/near commercial)

e.g. Elred/Plasmamelt @ 10 GJ/tonne

RESULT

1 kW/Capita FE

cf. 0.9 kW/capita FE in 1980

incl. 0.45 kW/capita NCE

Activity levels for a hypothetical developing country in a Warm climate, with Amenities (except for space heating) comparable to those in the WE/JANZ region(western Europe, JApan, Australia and New Zealand) in the 1970s

Activity	Activity Level
Residential	4 persons/HH
Cooking	Typical cooking level w/LPG stoves
Hot water	50 l of hot water/capita/day
Refrigeration	1 315 l refrigerator-freezer/HH
Lights	New Jersey (US) level of lighting
TV	1 colour TV/HH, 4 hours/day
Clothes Washer	1/HH, 1 cycle/day
Commercial	5.4 sq.m of floor space/capita(WE/JANZ ave, '75)
Transportation	0.19 autos/capita, 15,000 km/auto/year
Automobiles	(WE/JANZ ave, '75)
Intercity bus	1850 p-km/capita (WE/JANZ ave, '75)
Passenger train	3175 p-km/capita (WE/JANZ ave, '75)
Urban mass transit	520 p-km/capita (WE/JANZ ave, '75)
Air travel	345 p-km/capita (WE/JANZ ave, '75)
Truck Freight	1495 t-km/capita (WE/JANZ ave, '75)
Rail Freight	814 t-km/capita (WE/JANZ ave, '75)
Water Freight	1/2 OECD Europe ave, '78

Activity levels for a hypothetical developing country in a Warm climate, with Amenities (except for space heating) comparable to those in the WE/JANZ region(western Europe, JApan, Australia and New Zealand) in the 1970s (contd.)

Activity	Activity Level
Manufacturing	
Raw Steel	320 kg/capita (OECD Europe ave, '78)
Cemet	479 kg/capita (OECD Europe ave, '80)
Primary Aluminum	9.7 kg/capita (OECD Europe ave, '80)
Paper and Paperboards	106 kg/capita (OECD Europe ave, '79)
Nitogenous Fertilizers	26 kg N/ capita (OECD Europe ave, '79/ '80)
Agriculture	WE/JANZ ave, '75
Mining, Construction	WE/JANZ ave, '75

Technological Opportunities for a developing country in a Warm climate to use currently best available or advanced energy utilization technologies

Activity	Activity Level
Residential	
Cooking	70% efficient gas stove
Hot water	heat pump WH, COP=2.5
Refrigeration	Electrolux Ref/Freezer 475/kWh/year
Lights	Compact fluorescent Bulbs
TV	75 Watt unit
Clothes Washer	0.2 kWh/cycle
Commercial	Performance of Hamosand building
Transportation	(all uses , ex space heating)
Automobiles	Cummins/NASA Lewis Car @3l/100 km
Intercity bus	3/4 energy intensity in ‘75
Passenger train	3/4 energy intensity in ‘75
Urban mass transit	3/4 energy intensity in ‘75
Air travel	1/2 US energy intensity in ‘80
Truck Freight	0.67 MJ/t-km
Rail Freight	Electric rail @0.18 MJ/t-km
Water Freight	60% of OECD energy intensity

Technological Opportunities for a developing country in a Warm climate to use currently best available or advanced energy utilization technologies

Activity	Activity Level
Manufacturing	
Raw Steel	ave, Plasmasmelt & Elred Processes
Cemet	Swedish ave in 1983
Primary Aluminum	Alcoa process
Paper and Paperboards	Ave of 1977 Swedish design
Nitogenous Fertilizers	Ammonia derived from methane
Agriculture	3/4 of WE/JANZ energy intensity
Mining, Construction	3/4 of WE/JANZ energy intensity

Final energy use scenario for a developing country in a warm climate, with amenities comparable to those in the WE/JANZ region in the 1970s, but with currently best available or advanced energy utilization technologies

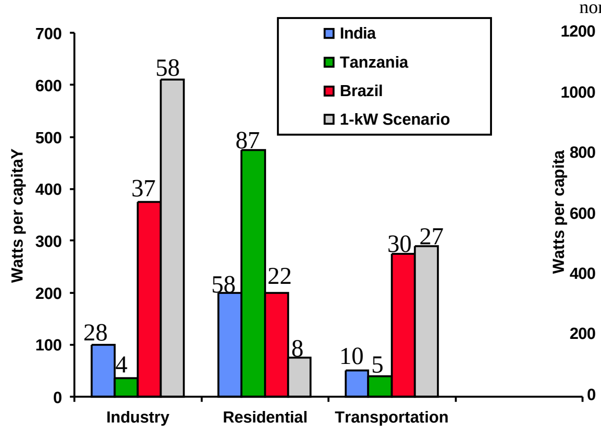
Activity	Average rate of energy use (Watts/Capita)		
Residential	Electricity	Fuel	Total
Cooking		34	
Hot water	29.0		
Refrigeration	13.0		
Lights	3.8		
TV	3.1		
Clothes Washer	2.1		
Subtotal	51.0	34	85
Commercial	22.0	-	22
Transportation			
Automobiles		107	
Intercity bus		26	
Passenger train	4.5	32	
Urban mass transit	2.0	8	
Air travel		21	
Truck Freight		32	
Rail Freight	5.0		
Water Freight		50	
	12.0	276	288

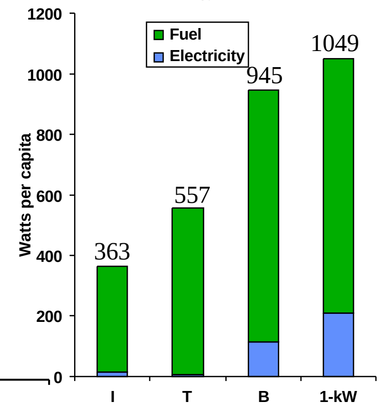
Final energy use scenario for a developing country in a warm climate, with amenities comparable to those in the WE/JANZ region in the 1970s, but with currently best available or advanced energy utilization technologies(con.)

Activity	**Average rate of energy use (Watts/Capita)**		
Manufacturing	**Electricity**	**Fuel**	**Total**
Raw Steel	28	77	
Cemet	6	54	
Primary Aluminum	11	26	
Paper and Paperboards	11	24	
Nitogenous Fertilizers	-	30	
Others	65	212	
Subtotal	121	429	550
Agriculture	4	41	45
Mining, Construction	-	59	59
TOTALS	210	839	1049

Final energy use per capita by sector and energy carrier, for India 1978, Tanzania in 1981, and the 1-kW scenario

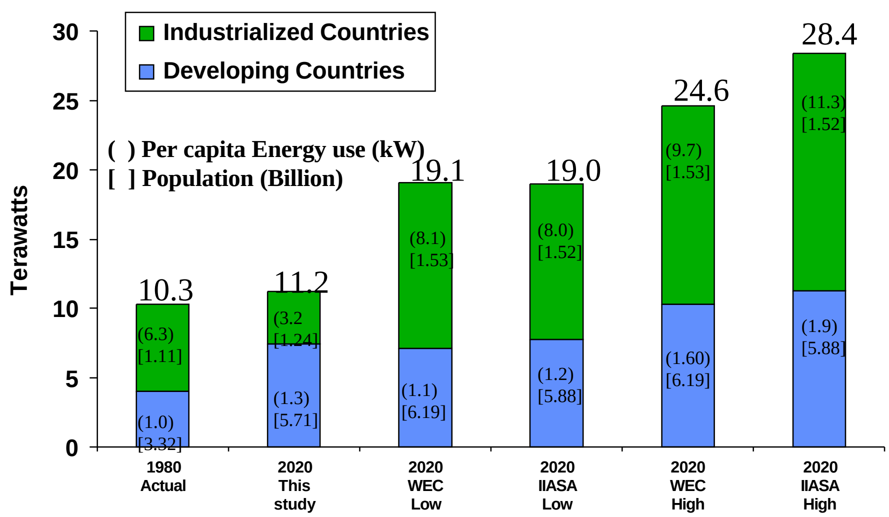
Nos. on top of the columns are final energy use per capita, nos. on the column are the carrier shares in percent and in parenthesis are the percentage share of noncommercial energy



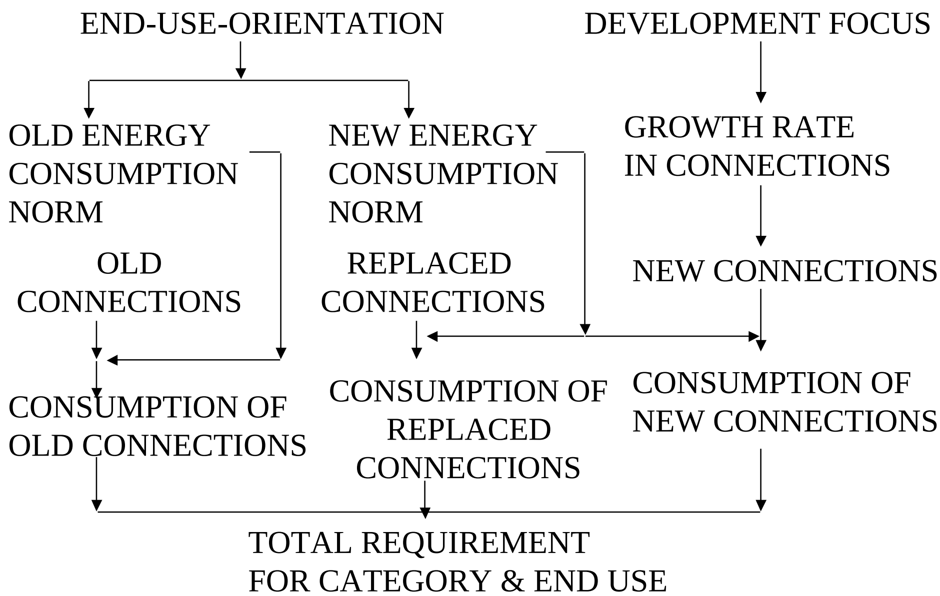


Numbers at the top of the columns are sectoral shares of percent of total final energy use

Alternative projections of golbal primary energy use disaggregated into the shares accounted for by the industrialized and the developing countries



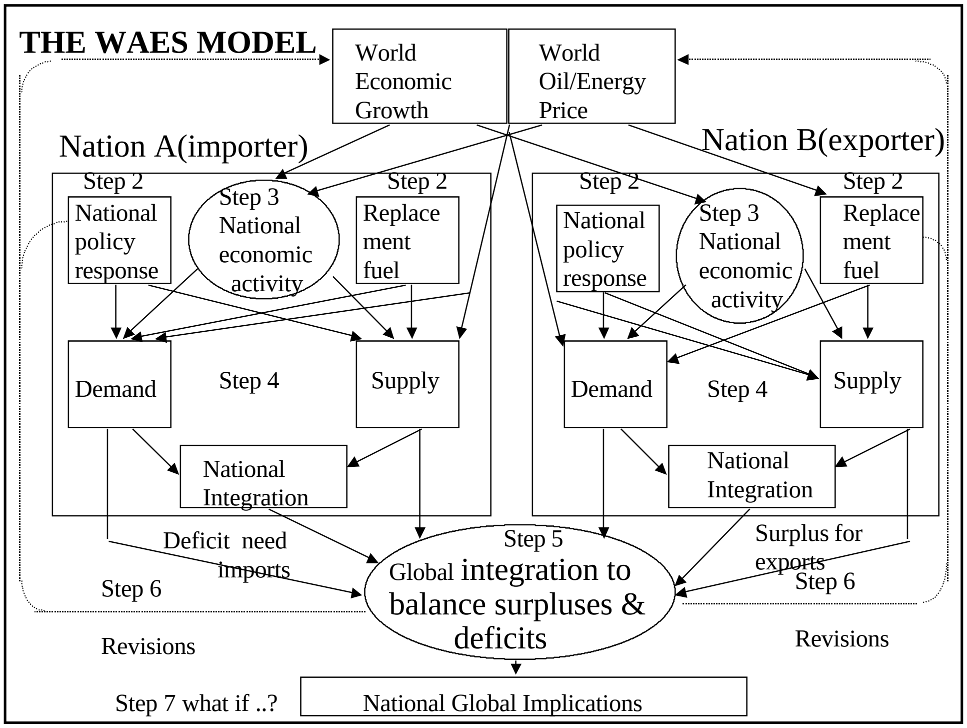
DEFENDUS ENERGY REQUIREMENT SCENARIO FOR YEAR B+J FOR EACH END-USE OF EACH CONSUMER CATEGORY

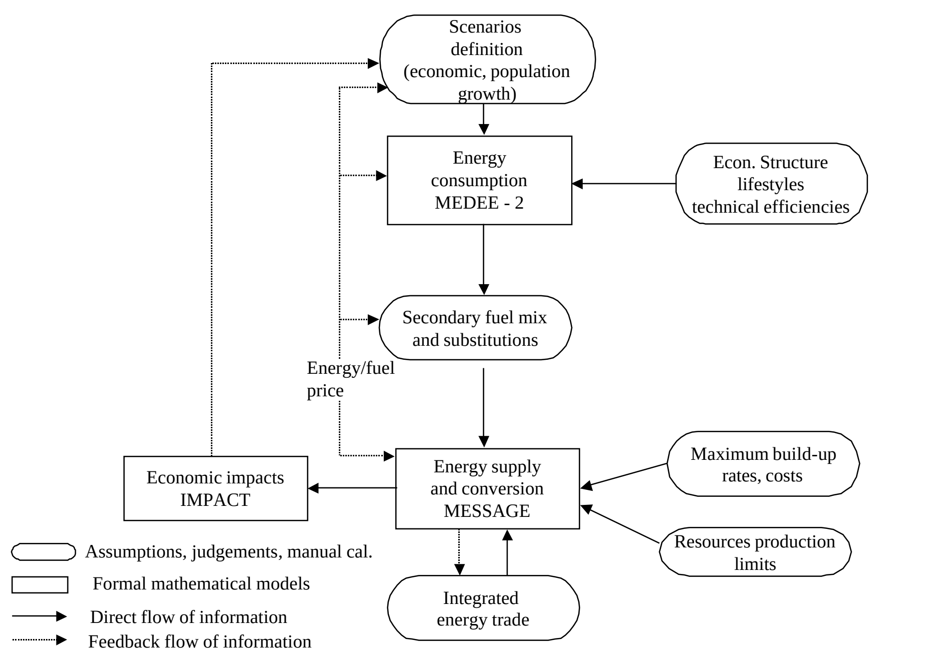


"OFFICIAL" ELECTRICITY PLAN (LRPPP) VS. DEFENDUS ELECTRICITY SCENARIO

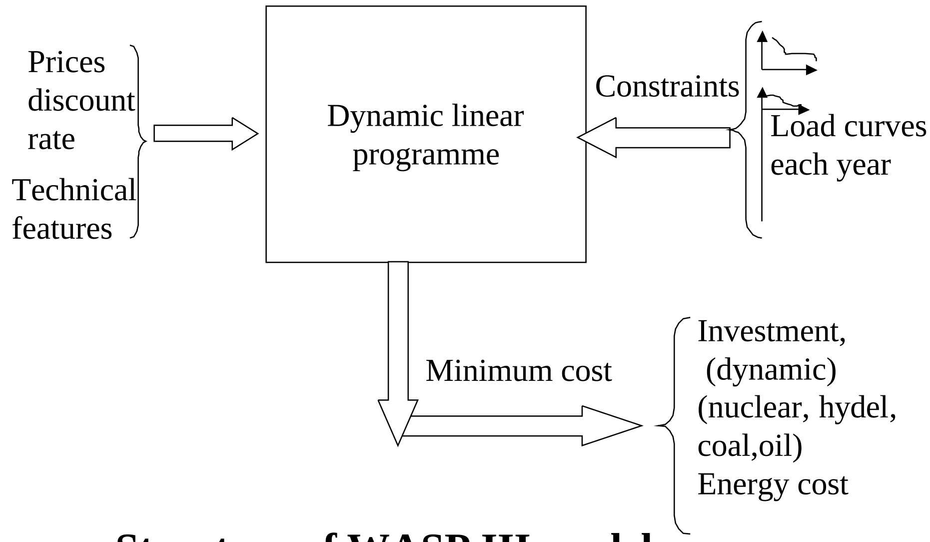
1986 CONSUMPTION = 7.554 TWH & INSTALLED CAPACITY = 2.53 GW

			DEFENDUS	LRPPP	DEFENDUS /LRPPP(%)
1986	DEMAND	TWH	10.431	12.013	87
1999	CONSUMPTION REQT.	TWH	14.646	38.729	38
1999	GENERATION REQT.	TWH	17.971	47.520	38
1999	CAPACITY REQT.	GW	3.976	9.397	42





IIASA set of energy model



Structure of WASP III model