

**KRISHNA BHARADWAJ
MEMORIAL LECTURE**

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CRISIS

a situation that does not permit
continuation of old patterns of
behaviour



ENERGY SYSTEM IS TRAPPED IN CRISES

- capital crisis
- performance crisis
- access or equity (= distribution) crisis
- environment crisis



ANNUAL INVESTMENT REQUIRED FOR CAPACITY EXPANSION

$$I = E(0) \cdot g(\text{CAP}) \cdot \text{UCOP}$$

$$= E(0) \cdot a \cdot g(\text{GDP}) \cdot \text{UCOP}$$

$E(0)$ = Capacity (In MW) in Base Year

$g(\text{CAP})$ = Growth Rate of Capacity

$g(\text{GDP})$ = Growth Rate of GDP

a = Ratio of growth rates of capacity & GDP

UCOP = Unit Cost of Capacity(Rs/kW)



OPTION #2: BELT-TIGHTENING

- Take (a . UCOP) as given/unchangeable
- $E(t-1)$ is also given
- Accept $I(t) = I(G) + I(ES) + I(NPS) + I(ML)$

And live with $g(GDP) = I(t) / \text{Constant}$

But this $g(GDP)$ may be less than $g(POP)$

If so, crisis!



OPTION#1 : ENSURE MINIMUM INVESTMENT

- Take (a . UCOP) as given/unchangeable
- $E(t-1)$ is also given

$$\hat{I}(t) = \text{constant} \times g(GDP)$$

If there is a $g(GDP)$ target, then ensure a minimum investment $I(t)$



SOURCES OF INVESTMENT

$$\mathbf{I(t) = I(G) + I(ES) + I(NPS) + I(ML) + I(FPS)}$$

But $I(G) \gg 0$, $I(ES) \gg 0$,

$I(NPS) \gg 0$, $I(ML) \gg 0$

^ $I(t)$ must come from $I(FPS)$

^ Go abroad with begging bowl



ENVIRONMENTAL CRISIS

Conventional energy production is associated with local and global impacts that degrade the environment



ENVIRONMENTAL CRISIS

- Hydroelectric projects \Rightarrow displace people and submerge forests
- Thermal power projects \Rightarrow produce acid rain and other forms of atmospheric & surface pollution
- Nuclear power plants \Rightarrow safety and radiation hazards.



EQUITY CRISIS

- Electricity systems expanded in the name of development
- But, they bypass the poor
- Less than half the HH benefit directly from its electricity
- Village electrification \neq HH electrification



ORIGIN OF THE CRISES

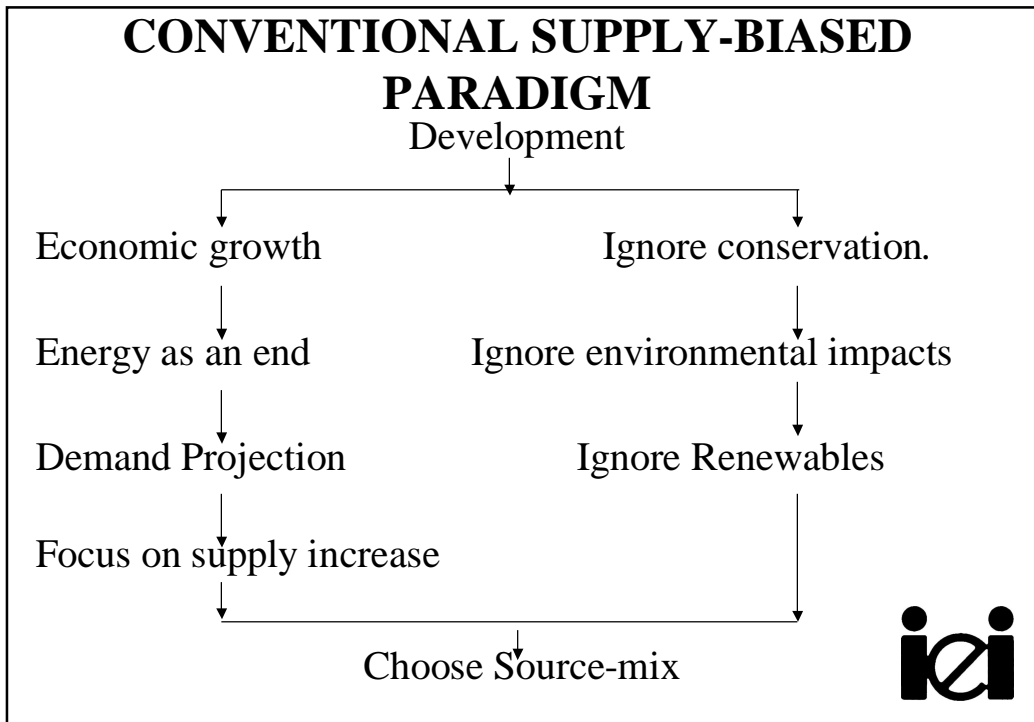
Conventional energy paradigm or mindset that determines the thinking of virtually all energy decision-makers and planners



CONVENTIONAL PARADIGM FOR ELECTRICITY PLANNING

Development = Growth = Energy =
Electricity = Centralized Generation
= Grid Transmission & Distribution





ENERGY-GDP “CORRELATION”

- Every economy consists of a number of energy-utilizing activities
- Each activity involves an energy intensity, I_j , and a fraction/contribution, $c_j = f_j(\text{GDP})$, to the GDP



TOTAL ENERGY DEMAND

E = Sum of energy demands of
various activities

$$E = \text{Sum } E_j = \text{Sum } [C_j \times I_j]$$
$$= \text{Sum } [f_j(\text{GDP}) \times I_j]$$

$$\hat{E} = [\text{Sum } f_j \times I_j] \times \text{GDP}$$



ENERGY DEMAND IS PROPORTIONAL TO GDP

if and only if
the term $[\text{Sum } (f_j \times i_j)]$
is a constant



ENERGY-GDP CORRELATION

is valid only during periods when there is no change in the economy's

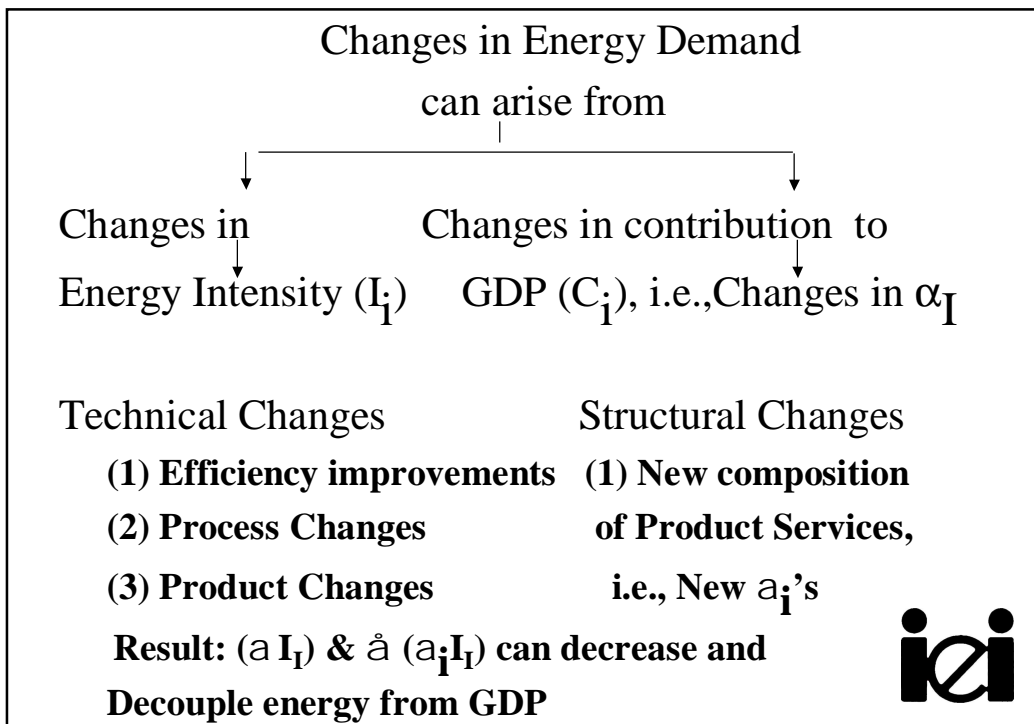
- (1) energy efficiency
- (2) structure




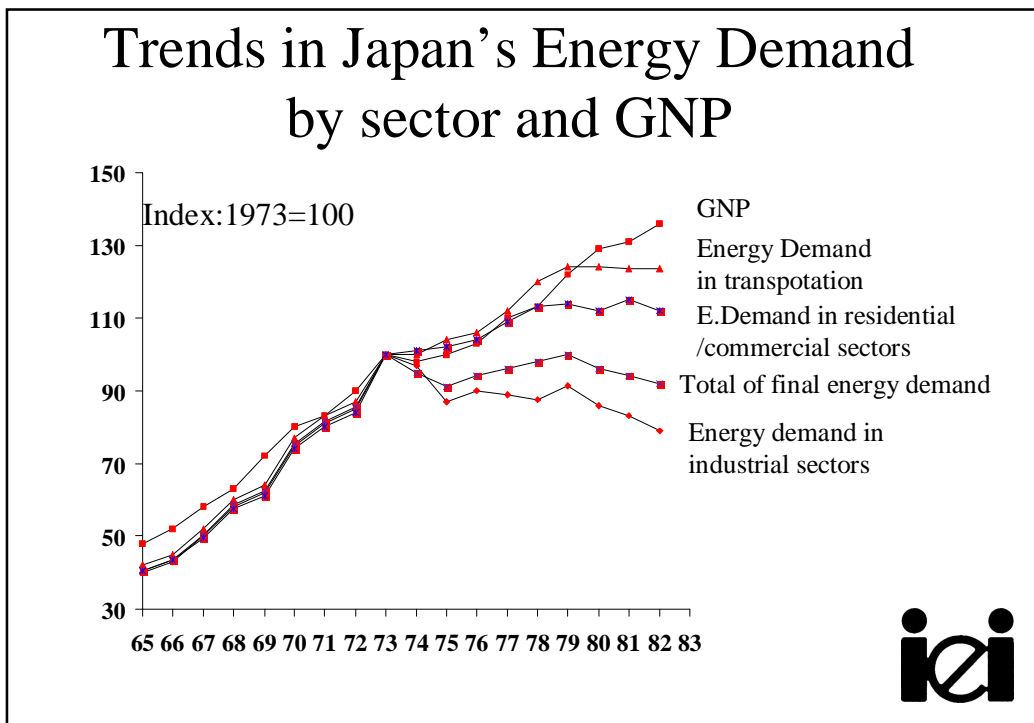
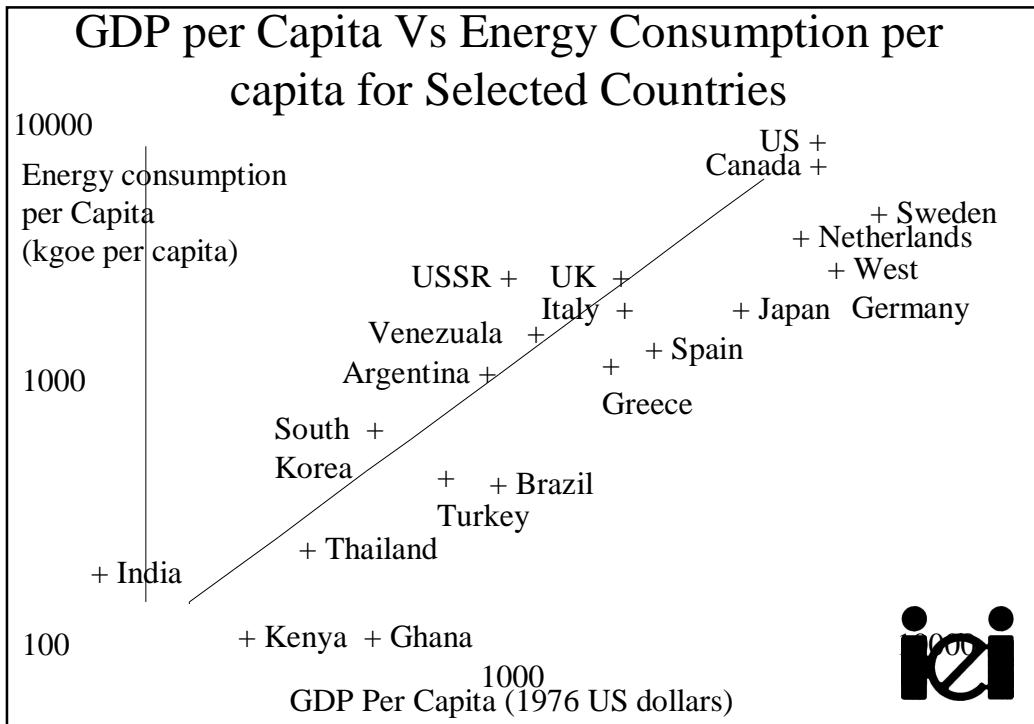
E-GDP PROPORTIONALITY BREAKS DOWN UNDER CHANGES

- of **energy intensity** due to efficiency improvements, process changes or product changes and/or
- of the **economy's structure**, i.e., the contributions of different activities to the GDP (e.g., the share of less-energy intensive activities increases)

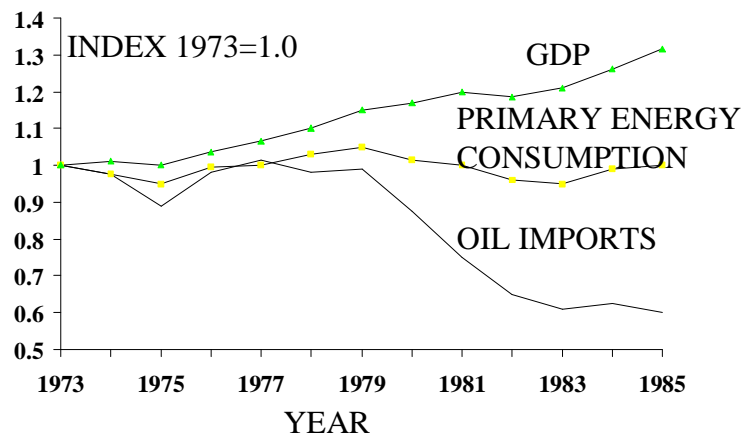




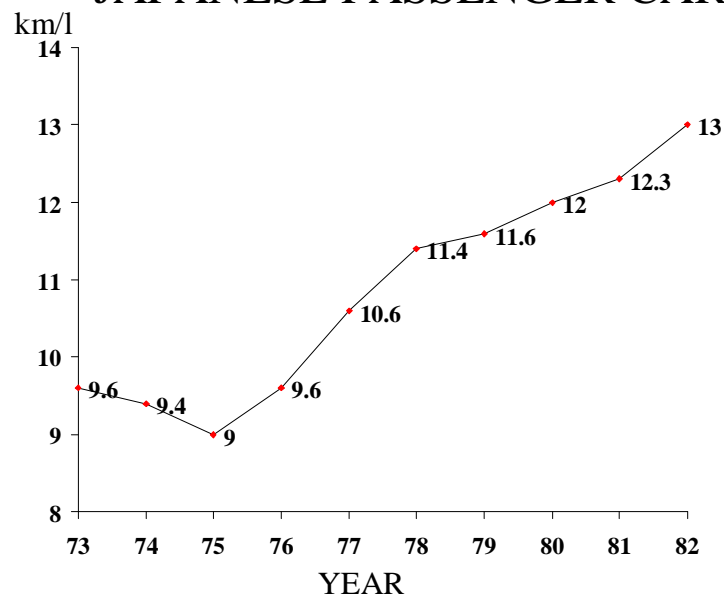
- DECREASE OF [SUM ($f_j \times I_j$)]**
- can offset an increase in GDP
 - reduce the coupling between GDP and energy
 - there can even be decoupling (decrease in energy consumption associated with an increase in GDP)
- 



OECD COUNTRIES 1973-1985



CHANGES OF FUEL EFFICENCY OF JAPANESE PASSENGER CARS



EFFICIENCY IMPROVEMENTS & ENERGY DEMAND

Implicit incorporation of EI via energy prices

$$ED = f(GDP, P) = A \cdot GDP^a \cdot P^{-b}$$

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

$$a = (\delta \ln ED / \delta \ln GDP)_P$$

= GDP elasticity of ED

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

= Price elasticity of ED



RELATION BETWEEN GROWTH RATES

ED, GDP and P are functions of time

$$\hat{\ln [ED(t)/ED(0)]} = a \ln [GDP(t)/GDP(0)] - b \ln [P(t)/P(0)]$$

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

$$ED(t)/ED(0) = (1 + g_{ED})^t \text{ and } \ln(1 + g_{ED}) \gg g_{ED}$$

$$\hat{g}_{ED} = a g_{GDP} - b G_p$$



SINGLE ELASTICITY EXPRESSION FOR ENERGY DEMAND

If $P(t) = P(0)$, i.e., $ED = \text{Constant } A \cdot \text{GDP}^a$

$$a = [d \ln ED] / [d \ln \text{GDP}]$$

$$g_{ED} = a \cdot g_{\text{GDP}} \quad \text{or} \quad a = g_{ED} / g_{\text{GDP}} =$$

GDP elasticity of ED = Ratio of growth rates
of ED and GDP



WB ESTIMATE OF ANNUAL CAPITAL REQUIREMENTS

$$\begin{aligned} \Delta ED/\text{yr} &= ED(1) - ED(0) = ED(0) \cdot g_{ED} \\ &= ED(0) \cdot a \cdot g_{\text{GDP}} \end{aligned}$$

$$\begin{aligned} \hat{\Delta I}/\text{yr} &= ED(0) \cdot g_{\text{GDP}} \cdot a \cdot \text{UCOP} \\ &= 600 \text{ GW} \times 4\% \times 1.5 \times \$2777/\text{kW} \\ &= \$100 \text{ billion/year} \end{aligned}$$



PROBLEMS WITH ELASTICITIES

Price elasticities cannot cope with following questions:

- 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?



PROBLEMS WITH ELASTICITIES

- Elasticities are difficult to measure and vary a great deal
- Price elasticities overemphasize role of prices
- Any change not explained by GDP (including non-price-related measures) is ascribed to price



PROBLEMS WITH ELASTICITIES

- Elasticities are black boxes that do not 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



DOUBLE ELASTICITY MODEL

with Explicit Incorporation of EI

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

P^{-b} = Price-induced efficiency improvement

$(1+c)^n$ = Non-price-induced efficiency improvement



SUBSIDIES TO THE POWER SECTOR

- Subsidies promote waste and discourage efficiency
- There should be no net subsidies to power sector
- Cross-subsidies (from one consumer category to another) permissible with consumer consent up to a limit



DISCOURAGING CONSUMERS FROM WASTING ELECTRICITY

- Two options: tariff increases versus efficient equipment
- If consumers' demand is *inelastic* (i.e., does not decrease even after price increases), tariff increase may not reduce electricity demand
- Improving equipment efficiency is better than mere tariff increases



BETTER TO SUBSIDIZE EFFICIENT EQUIPMENT THAN SUBSIDIZE ELECTRICITY

- Some consumers may be unable to pay first cost of efficient equipment
- Financing schemes to lower/defer first costs for promotion of improved equipment and reduction in energy demand
- Subsidy (with sunset clause) should be restricted to emerging technologies



TECHNO-ECONOMIC MODELS

Σ End-uses \longrightarrow Σ UE \longrightarrow Σ FE \longrightarrow ED

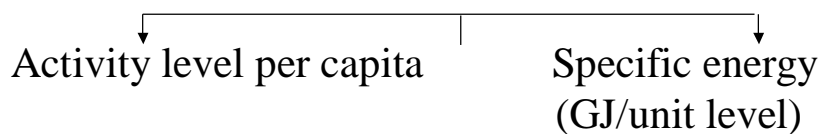
End-use data \longrightarrow not always available

So, work with activities

Economy = Σ Sectors

= Σ Sectoral activity

Each sectoral activity



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



A THOUGHT EXPERIMENT

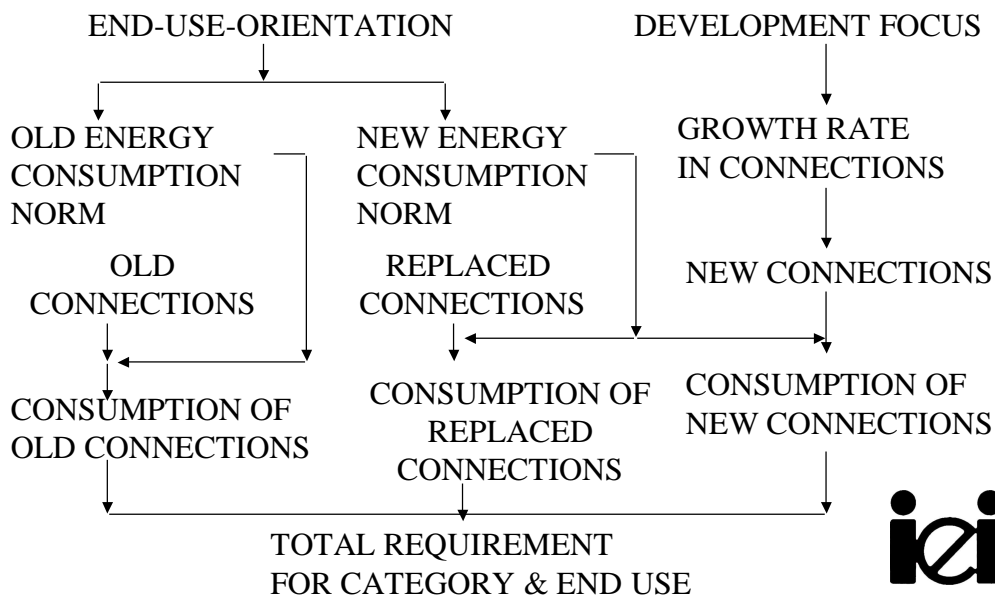
$$E(\text{total}) = \sum [(\text{Activity level})_i * (\text{Specific Energy})_i]$$

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

Result \supset 1 kW/capita Final Energy
 versus 0.9 kW/capita Final Energy in 1980
 including 0.45 kW/capita NCE



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



CONVENTIONAL PARADIGM FOR ENERGY

- **GR**owth-oriented **S**upply-Sided **CON**sumption-biased (GROSSCON) Paradigm
- Magnitude of energy consumption is deemed to be the indicator of development



A NEW PARADIGM FOR ENERGY

- What human beings and their activities require is not energy *per se* but the work that energy performs and the services that energy provides (heat for cooking, warmth, process heat, illumination, mobility, etc.)
- Development requires increases in energy services



INCREASING ENERGY SERVICES

- Not only by increasing the supply of energy to the devices (lamps, heaters, motors vehicles, etc)
- But also by increasing the efficiency of these devices and/or by shifting to more efficient energy carriers



SWITCH FROM KEROSENE WICK LAMPS TO 20 W FLUORESCENT TUBELIGHTS

- Illumination increases about 19 times but utilization of input energy decreases to only one-ninth initial value (with kerosene)
- because of 420 times greater efficiency of 20 W fluorescent tubelights compared to kerosene wick lamps



BEFORE SWITCH TO FLUORESCENT TUBELIGHTS

Households consumed far more energy but
enjoyed far less lighting energy service



IMPROVEMENT IN THE LEVEL OF ENERGY SERVICES

- by increasing energy consumption through an increase of energy supplies (CENTs or DECENTs) and/or
- by increasing the efficiency with which end-use devices utilize energy, i.e., by end-use efficiency improvements (EUEIs)



**THIS ADVANCE IN
DEVELOPMENT HAS BEEN
ACHIEVED ALONG WITH A
DECREASE IN THE
CONSUMPTION OF ENERGY**



**GENERAL PARADOX OF
ENERGY IN DEVELOPING
COUNTRIES**

High levels of energy consumption with
low levels of energy services



IT IS THE LEVEL OF ENERGY SERVICES -- AND NOT THE MAGNITUDE OF ENERGY CONSUMPTION -- THAT MUST BE TAKEN AS THE INDICATOR OF DEVELOPMENT



REDUCTION OF INVESTMENT

[with $E(0)$ and $g(\text{GDP})$ as given]

- Decrease a , the coupling factor, through efficiency improvements and/or
- Decrease UCOP, the unit cost of capacity in Rs/kW (by avoiding T&D losses through decentralized generation and/or cogenerating electricity)



LEAST-COST MIX

- Include **saving** options
- Don't restrict generation options to centralized options and fossil-fuel/ non-renewable options
- Include **decentralized** options as well as **renewables**



OPTION #3--> IRP APPROACH

- $E(t-1)$ given
- Minimum growth rate of GDP given
- Scrutinize (a.UCOP) in order to decrease a and/or decrease UCOP



OPTION #3--> IRP APPROACH

1. EUEI \dot{Y} , a β (greater GDP “bang” for lower energy “buck”)
2. Cost of CENTs β through EI in generation (PLF $\dot{Y} \supset$ availability \dot{Y}) through reduction of T & D losses (technical and non-technical)
3. DECENT \supset grid-connected (cogeneration) or stand-alone (at construction sites)



OPTION #3--> IRP APPROACH

a β and/or UCOP $\beta \therefore I(t) \beta$

Thus Capital crisis eased

Also, Performance crisis eased

Environment crisis eased

Access crisis eased



THREE RESOURCES

- CENTS (Conventional)
- DECENTS (Non-conventional)
- EUEIs



**COSTS OF ELECTRICITY FROM
SOURCES SUCH AS BIOMASS,
WIND, SMALL HYDEL,
PHOTOVOLTAICS, ETC., ARE
FALLING RAPIDLY**



THREE ENERGY OPTIONS FOR INDIA

- **“Copying the worst”** (early industrializers with the highest maxima)
- **“Copying the best”** (latest industrializers (e.g., Japan) showing the lowest maxima)
- **“Beating the best”** through technological leap-frogging



THE NEW CHALLENGE

- **Reducing the coupling** between GDP growth and energy consumption
- **Identifying & implementing a least-cost mix** of generation & saving options for increasing energy services.



POWER SECTOR MUST

- acquire a human face
- become an instrument of Sudevelopment
- ask: electricity for whom? what? how (efficiently)?
- emphasize energy services for the poor



POWER SECTOR MUST

acquire a development focus
and
an end-use orientation
directed towards energy services.



WHAT IS REQUIRED

- A new paradigm for energy
- A **DE**velopment-**F**ocussed **END-Use**-oriented **S**ervice-directed or **DEFENDUS** paradigm to rescue us from the crises



BENEFICIARIES OF IRP Government/Energy Ministry

- To avoid gross excess capacity of Cents
- To maximize funds for other development activities by implementing least-cost mix
- To overcome funds constraint on capacity expansion
- To guide public sector investment in capacity expansion



BENEFICIARIES OF IRP Government/Energy Ministry

- To define niche for Decents
- Least environmental impact mix
- To arrive at PURPA-like basis for PPAs
- To provide rational basis for formulating enabling policies for energy technologies
- To provide rational basis for funding R & D for energy technologies



BENEFICIARIES OF IRP: ELECTRICITY UTILITY

- To define niche for Decents
- To identify cost-effective DSM/EI measures



BENEFICIARIES OF IRP: ELECTRICITY REGULATORY COMMISSION

- To define lowest Marginal Cost Price of electricity
- To define corresponding rational tariff
- To evaluate PPAs on PURPA-like avoided cost basis



BENEFICIARIES OF IRP: CONNECTED CONSUMERS

- To know lowest Marginal Cost Tariffs
- To be protected against tariff distortions by high-cost PPAs



BARRIERS TO IRP

Dominance of old paradigm

- Decision making based on supply-biased paradigm
- Any-power-is-better-than-no-power syndrome

Costing of Energy/Power

- Stand-alone rather than Marginal Costing



INSTITUTIONAL BARRIERS

- Decision-maker only responsible for supply side management but not for DSM
- Decision-maker profits from consumption increase
- Vested interests (in private/public sector) that benefit from business-as-usual approaches and practices and, therefore, resist change
- Institutional obstacles (including monopoly position of utilities and lack of appropriate fora and rules for interaction between relevant organizations).



MARKET BARRIERS TO IRP

- Subsidies (open/hidden) to conventional energy particularly fossil fuels
- Electricity prices do not reflect costs
- Market prices do not reflect environmental costs and damage
- Market prices mask environmental advantages of the new and cleaner energy options



MARKET BARRIERS TO IRP

- Limited access to information
- First cost sensitivity (where decisions are based on initial, rather than life-cycle, costs)
- Indifference to energy costs leading to limited attention to alternative energy options.



SUCCESSFUL IRP: NECESSARY AND SUFFICIENT CONDITIONS

- National Policy Commitment
- Agency that can control generation & influence demand
- IRP capacity backed by IRP exercises
- Constraints (e.g., capital, environmental) on supply expansion
- Marginal Cost Pricing as basis for arriving at PPAs
- Marginal Cost Pricing as basis for tariffs

