Lecture - 2

Understanding and Analysis of Energy Demand

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Outline

- The role energy in the economics
- What is energy demand
- Fundamental economics theory
- Energy Demand Indicators
- Energy Demand Analysis
- Energy Demand Forecasting

The role of energy in the economics

Key role of energy sector in the economic activities

The key role of the energy sector in the economic activities of any economy arises because of the mutual interdependence between economic activities and energy. For example, the energy sector uses inputs from various other sectors(industry, transport, households, etc.) and is also a key input for most of the sectors. These interrelations influence the demand for energy, possibilities of substitution within the energy and with other resources (capital, land, labour and material), supply of energy and other goods and services, investment decisions, and the macro-economic variables of a country (economic output, balance of payment situations, foreign trade, inflation, interest rate, etc.). Once again, the national level institutions (including the rules and organisations like government, judiciary, etc.) both influence and get influenced by these interactions.

Energy and macro-economics

The macro-level influences arise broadly from:

a) The level of economic activities and its evolution over time;
b) Interdependence of energy and other economic activities as well as interactions among economic activities;
c) The structure of each activity and its evolution over time;
d) The technical composition and characteristics of the economic activities and its evolution over time;
e) The institutional arrangement that provides the enabling environment for different activities to flourish and its evolution;
f) Macro-management of the economy and its interaction with the institutional arrangement.

What is energy demand

Energy demand vs. energy consumption

A distinction is sometimes made between energy consumption and energy demand.

- Energy demand describes a relationship between price (or income or some such economic variable) and quantity of energy either for an energy carrier (e.g. electricity) or for final use (such as cooking). It exists before the purchasing decision is made (i.e. it is an ex ante concept—once a good is purchased, consumption starts). Demand indicates what quantities will be purchased at a given price and how price changes will affect the quantities sought. It can include an unsatisfied portion but the demand that would exist in absence of any supply restrictions is not observable.
- Consumption on the other hand takes place once the decision is made to purchase and consume (i.e. it is an ex post concept). It refers to the manifestation of satisfied demand and can be measured.
- Energy demand is a derived demand as energy is consumed through equipment. Energy is not consumed for the sake of consuming it but for an ulterior purpose (e.g. for mobility, for producing goods and services, or for obtaining a certain level of comforts, etc.).

Source: Bhattacharyya

Understanding energy demand

- ✓ Energy demand is a derived demand that arises for satisfying some needs which are met through use of appliances. Hence, demand for energy then depends on the demand for energy services and the choice of energy using processes or devices.

- ✓ End-use service demand is affected by the cost of energy but also by other factors such as climatic conditions, affordability (or income of the decision-maker), preference for the end-use service, etc. Similarly, demand for end-use appliances depends on the relative prices of the appliances, relative cost of operation, availability of appliances, etc.

Fundamental economic theory

Basic microeconomic theory

- The demand for a good is represented through a demand function which establishes the relation between various amounts of the good consumed and the determinants of those amounts. The main determinants of demand are: price of the good, prices of related goods (including appliances), prices of other goods, disposable income of the consumer, preferences and tastes, etc.
- To facilitate the analysis, a convenient assumption (known as ceteris paribus) is made which holds other determinants constant (or unchanged) and the relation between price and the quantity of good consumed is considered. This simple functional form can be written as follows: $q = f(p)$, where q is the quantity demanded and p is the price of the good. The familiar demand curve is the depiction of the above function.

Source: Bhattacharyya

Consumer Demand for Energy: Utility Maximization Problem

- The microeconomic basis for consumer energy demand relies on consumers' utility maximization principles. Such an analysis assumes that
  - Consumers know their preference sets and ordering of the preferences.
  - Preference ordering can be represented by some utility function and
  - The consumer is rational in that she will always choose a most preferred bundle from the set of feasible alternatives.

Source: Bhattacharyya

Budget constraint

Assume that an individual has 100 dollars to allocate between energy E and other goods X. One unit of energy costs 5 dollars while one unit of other goods costs 20 dollars. Accordingly, the individual can buy 20 units of energy or 5 units of other goods or a combination of these goods as shown by the shaded area of figure 3.3

In equation form this is written as $100 = 5E + 20X$

Consider a utility function $U = X^{0.5}E^{0.5}$

Fig. 3.2 Budget constraint

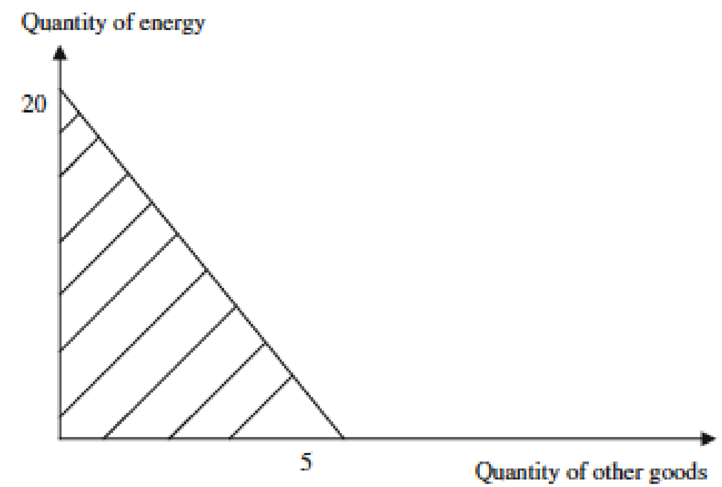
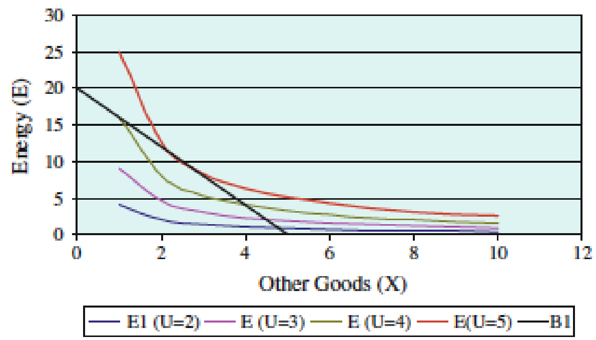
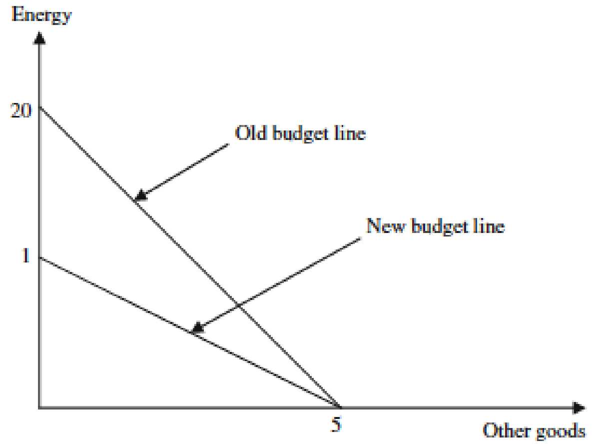


Fig. 3.3 Utility maximisation



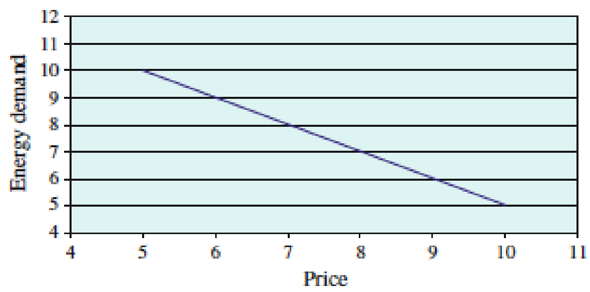
The combinations of X and E for various levels of utility (e.g. U = 2, 3, 4 and 5) can be easily determined for this function (see Fig. 3.3). These curves are called indifference curves. The optimal demand for energy and other commodities could be determined for the given individual from the budget line and the indifference curves (see Fig. 3.3).

Fig. 3.4 Effect of changes in energy price on the budget line



Now consider that the price of energy changes to 10 per unit while the price for other goods remains unchanged. Naturally, the consumer now will be able to consume only 10 units of energy or 5 units of other goods or some combinations of energy and other goods (as shown in Fig. 3.4). Following the method indicated above, the new optimal combination is found and in this particular case, the individual would consume 5 units of energy and 2.5 units of other goods (i.e. just 50% reduction of energy demand). This gives another pair of points on the demand curve.

Fig. 3.5 Energy demand curve of an individual

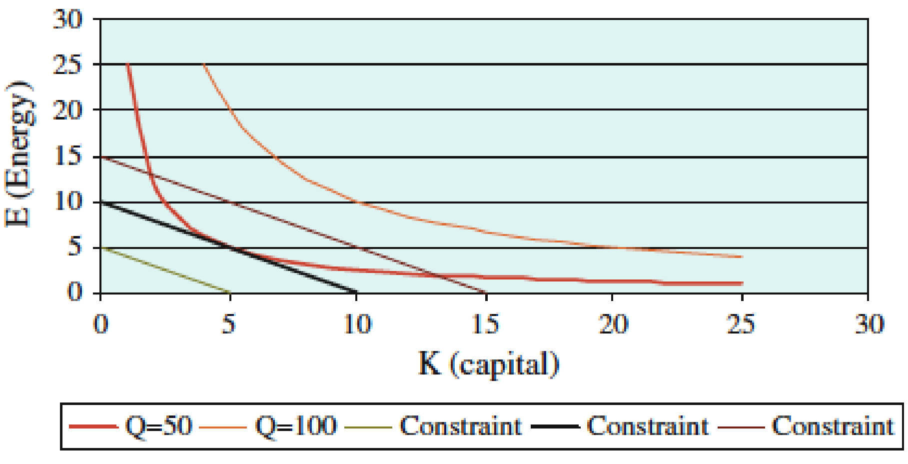


The individual's energy demand schedule can now be drawn using these points (see Fig. 3.5). As you have noticed, in the entire process, we have only changed energy prices while keeping other variables unchanged (i.e. assumed that ceteris paribus condition holds). In Fig. 3.5, the demand curve is downward sloped as is expected.

Cost Minimization Problem of the Producer

- In the case of producers, the theory of the producers is used to determine the demand for factors of production. In the production process, it is normally possible to replace one input by the other and the producer would try to find the combination of inputs that would minimize the cost of production.

Fig. 3.6 Optimal input selection for the firm



Source: Bhattacharyya

Energy demand

"Demand for energy is derived from wishes to use energy to obtain desired services. Energy demand depends primarily on demand for desired services, availability and properties of energy conversion technologies, and costs of energy and technologies used for conversion".

- Gasoline is nasty – why do you buy it?
- The demand for energy (gasoline) is ***derived*** from the demand for energy services (transportation), e.g.
  - Food preparation, heating, lighting, cooling, loud music…
- The technology of producing any particular energy service can be summarized in a production function:

$$Q = F(K, L, E, M)$$

  - Capital is important in the production of most energy services
  - Some studies find that capital and (particularly electric) energy are *complements*: increasing the price of one decreases demand for both (coffee & cream)
- Historically there has been enormous progress in technologies for energy services

Source: MIT

Short Run Energy Demand

- Begin with two fundamental functions:
  - Demand function for some energy service:

    ES = D(EScost, Ps, income I Ks, "tastes")

    EScost = per-unit cost of the service (e.g., lighting)
    Ks = capital stocks & tastes are fixed in the short run
  - Production function for that energy service:

    ES = F(E, Ms, Ls I Ks, technology)

    Ms = materials of various sorts
- Given all prices, including P_E, solve for E demand by
  - Finding least-cost inputs to produce ES: E*(ES, Ps,…), EScost* (ES, P's,…)
  - Then substituting into ES demand function, get E*(Ps, …)

Source: MIT

Consider - Electricity for Lighting

- Start with the two basic functions:
  - *Demand* for lighting (lumen-hours): $L = a(Lcost)^{-b}$, a and b positive constants, Lcost is cost per lumen-hour
  - b = - (dL/dLcost)(Lcost/L) = price elasticity of demand for lighting, the limiting ratio of percentage changes
  - In the SR bulbs in the house are fixed, so *production function* is just L = eE, e is a positive constant, E is electricity

- Given price of electricity, P_E($/kwh), solve for $/lumen, then substitute in demand function (check units!)
  - L(lumens)=e(lumens/kwh)E(kwh)
  - Lcost*($/lumen) = P_E($/kwh)/e(lumen/kwh)
  - Substitute & solve: $L = eE = a(P_E/e)^{-b}$; $E = a(P_E)^{-b}(e)^{b-1}$

Source: MIT

Consider - Electricity for Lighting (cont.)

- Here the elasticity of demand for electricity to produce lighting equals the elasticity of demand for lighting; this is *not* a general property of derived demand
  - Derived demand for an input (electricity) can be more or less elastic than the demand for the output (lighting) from which it is derived
- Note that if $b > 0$, making lighting more efficient (raising e) would raise the demand for lighting – by lowering the cost
  - Making cars more efficient makes driving cheaper, all else equal, and should increase driving – the "rebound effect" of CAFE
- If $b > 1$, so demand for lighting is price-elastic, making lighting more efficient raises the demand for *electricity*
  - Might be plausible in this case…?
  - Some have argued that CAFE standards increase the demand for gasoline this way, but it seems $b < 1$ in fact; small rebound

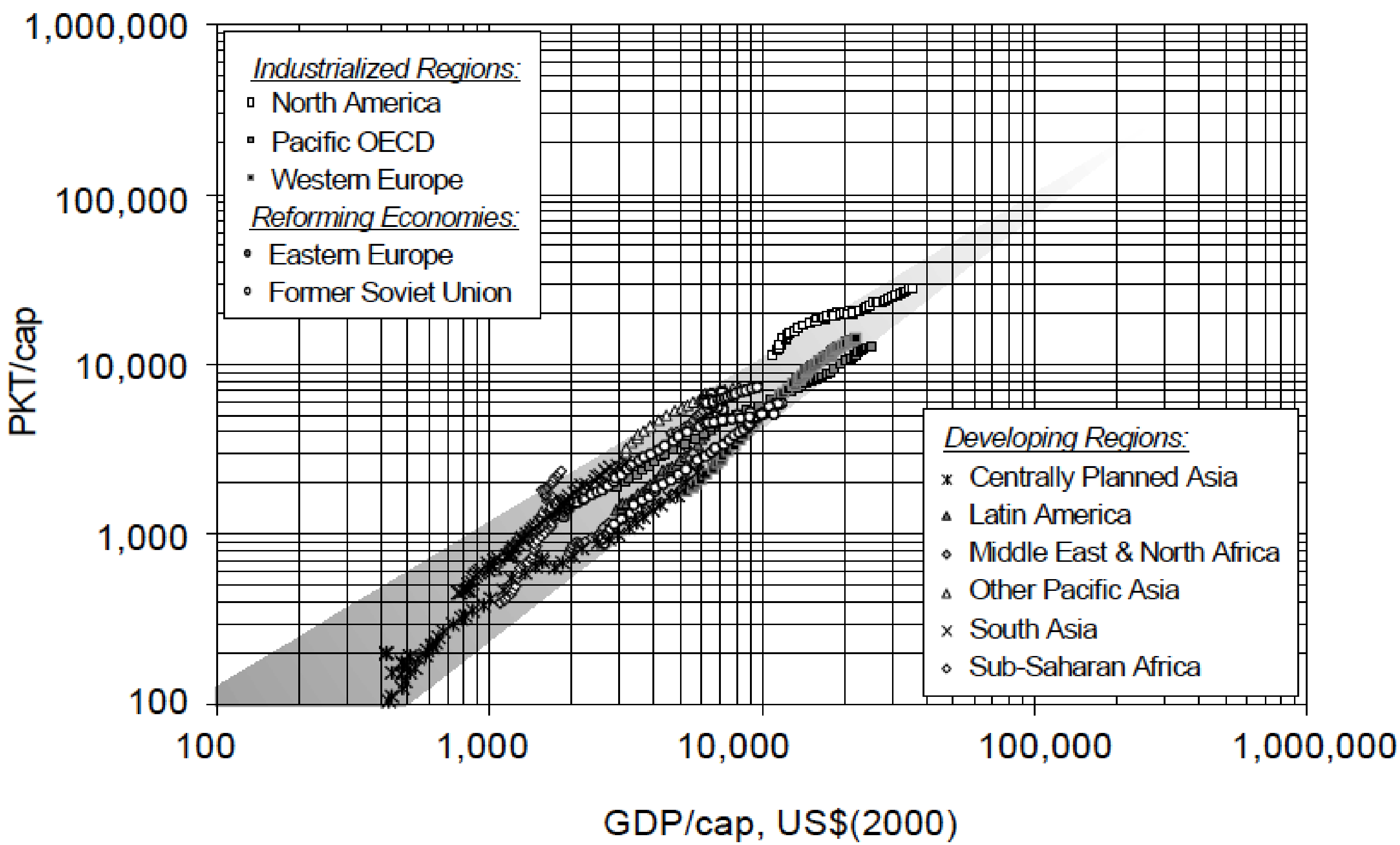
9

Source: MIT

Longer Run Energy Demand

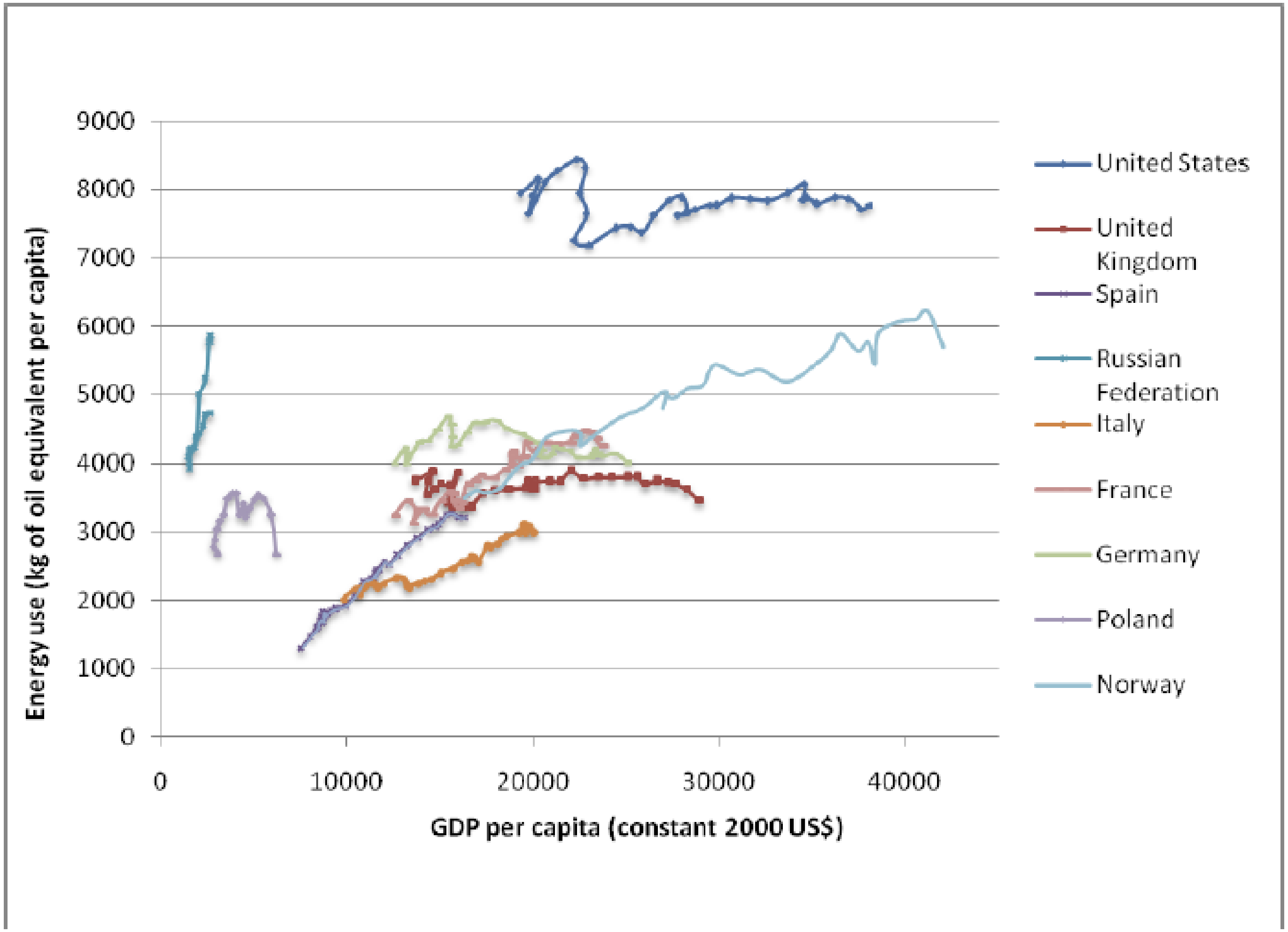
- Consider my demand for gasoline
  - In the SR, with my car given, I can only respond to price or income changes by changing driving: *the output effect*
  - In the LR, if changes persiste, I can change my car, changing the relation between gasoline demand and driving: *the substitution effect*
- Basic principle (Samuelson): Expect higher LR price or income elasticity than SR since more flexibility $\Rightarrow$ greater ability to respond $\Rightarrow$ greater response
- Most energy-transforming and energy-using capital is <u>very</u> long-lived: houses, cars, etc.
  - Past investment decisions shape future costs & options
  - Cost of rapid cuts in CO_2: either drastically cut energy services or scrap & replace existing assets prematurely

Income Also Affects Demand



Passenger Kilometers Traveled (PKT) per Capita

Energy use vs. GDP per kapita



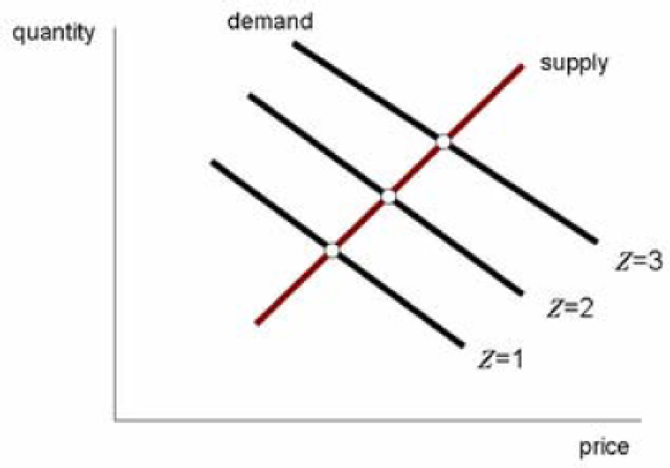
Source: World Bank (2010).

Demand Estimation: Identification

- Early demand studies for agricultural products found demand curves sloped up

  How could this happen?

- The classic *identification problem:* shifts in demand traced out the supply curve



- Teaching note works out a simple example with linear supply & demand curves:
  - Not possible *in principle* to estimate demand without data on some variable that shifts the supply curve
  - Similarly, need demand shifters to estimate the supply curve
  - Generally use special techniques to get "good" estimates

Demand Estimation: Dynamics

- "Partial adjustment" models let SR response (to temporary Δ) & LR response (to permanent Δ) differ
  - $E(t) - E(t-1) = \lambda[E^*(Ps, Y, \text{tastes}, \ldots) - E(t-1)]$, $0 < \lambda < 1$
    E^* is a model of *long-run* equilibrium demand; gives demand in the limit if Ps, Y constant for a long time
  - Put E(t-1) on the right, find coeffs that "best fit" data:
    $E(t) = \lambda E^*(Ps, Y, \text{tastes}, \ldots) + (1- \lambda)E(t-1)$
    Response to temporary change in Ps = λ reponse to permanent change
    Coefficient of lagged demand gives λ, can then get E^*
- Other approaches are also used
  - E.g., Huntington (see teaching note) decomposes oil P into P_{max}, $[P - P_{max}]$, finds P_{max} has larger effect
- Very durable assets (esp. structures, cities) in energy $\Rightarrow$ full response to changes in price, income, … can take a LONG time

- Estimated LR price & income elasticities for energy generally <u>much</u> larger than SR elasticities (small λ)
- SR income & price elasticities generally < 0.5 – limited ability to respond with fixed capital assets
- Gasoline & electricity are the most studied; ranges for rich countries from teaching note:

		Gasoline	Electricity
Price Elasticity	Short-Run	.15 – .25	.20 – .40
	Long-Run	.50 – .70	.50 – .80
Income Elasticity	Short-Run	.30 – .50	.15 – .30
	Long-Run	.60 – 1.10	.80 – 1.10

Demand functions are NOT constants of nature

- 1970 electricity wisdom: income e > 1, price e ≅ 0.1; Res. = 33%, Comm. = 25%, Ind. = 41% of end use

  Let's try to "forecast" long-term changes in demand

Period	GR GDP	GR Real P_E	GR Elect Use
1950-60	3.50	-2.40	10.61
1960-70	4.20	-3.22	7.30
1970-80	3.18	3.45	4.17
1980-90	3.24	-0.77	3.08
1990-00	3.40	-1.66	2.39
2000-07	2.40	1.62	1.27

- What happened?

Indicators of energy demand

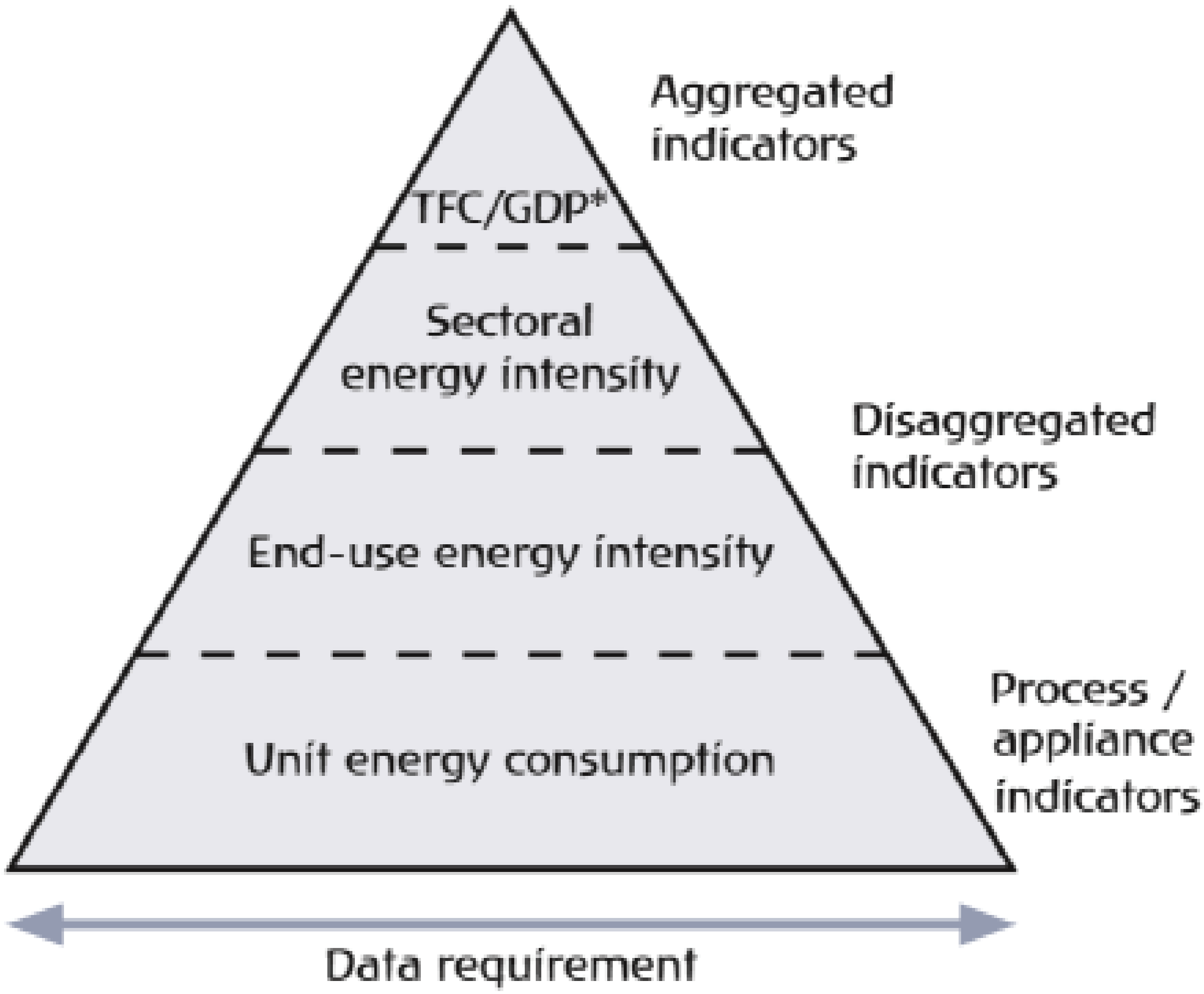
Indicator of energy demand

Annual growth rate is another indicator commonly used to describe the trend. This can be on an annual basis or an average over a period. Table 3.1 presents the formula commonly used.

Table 3.1 Mathematical relationships for simple indicators of trend

Indicator	Formula	Parameter description
Year-on-year growth rate	$a = (E_{t+1} - E_t)/E_t$	Where a = annual growth in demand, E_{t+1} = energy consumption in year $t + 1$ and E_t = energy demand in year t
Annual average growth rate over a period	$E_{T1} = E_{T0}\left(1 + a_g\right)^{(T1-T0)}$ $a_g = \left(\frac{E_{T1}}{E_{T0}}\right)^{1/(T1-T0)} - 1$	Where E_{T1} = energy demand in period $T1$ and E_{T0} = energy demand in period $T0$, a_g = annual growth rate
Demand elasticities	$e_t = \frac{(\Delta EC_t/EC_t)}{(\Delta I_t/I_t)}$	Where t is a period given EC is energy consumption I is the driving variable of energy consumption such as GDP, value-added, price, income etc. Δ is the change in the variable
Energy intensity (for a single energy)	$\mathrm{EI}_t = \frac{E_t}{I_t}$	EI_t = energy intensity for year t, E_t = energy consumption in year t and I_t = value of the driving variable (say GDP or value added)
Energy intensity in case of aggregated fuels	$\mathrm{EI}_t = \frac{\sum_{i=1}^{n} E_{it}}{I_t}$	Where E_{it} = energy consumption of ith type of fuel in year t

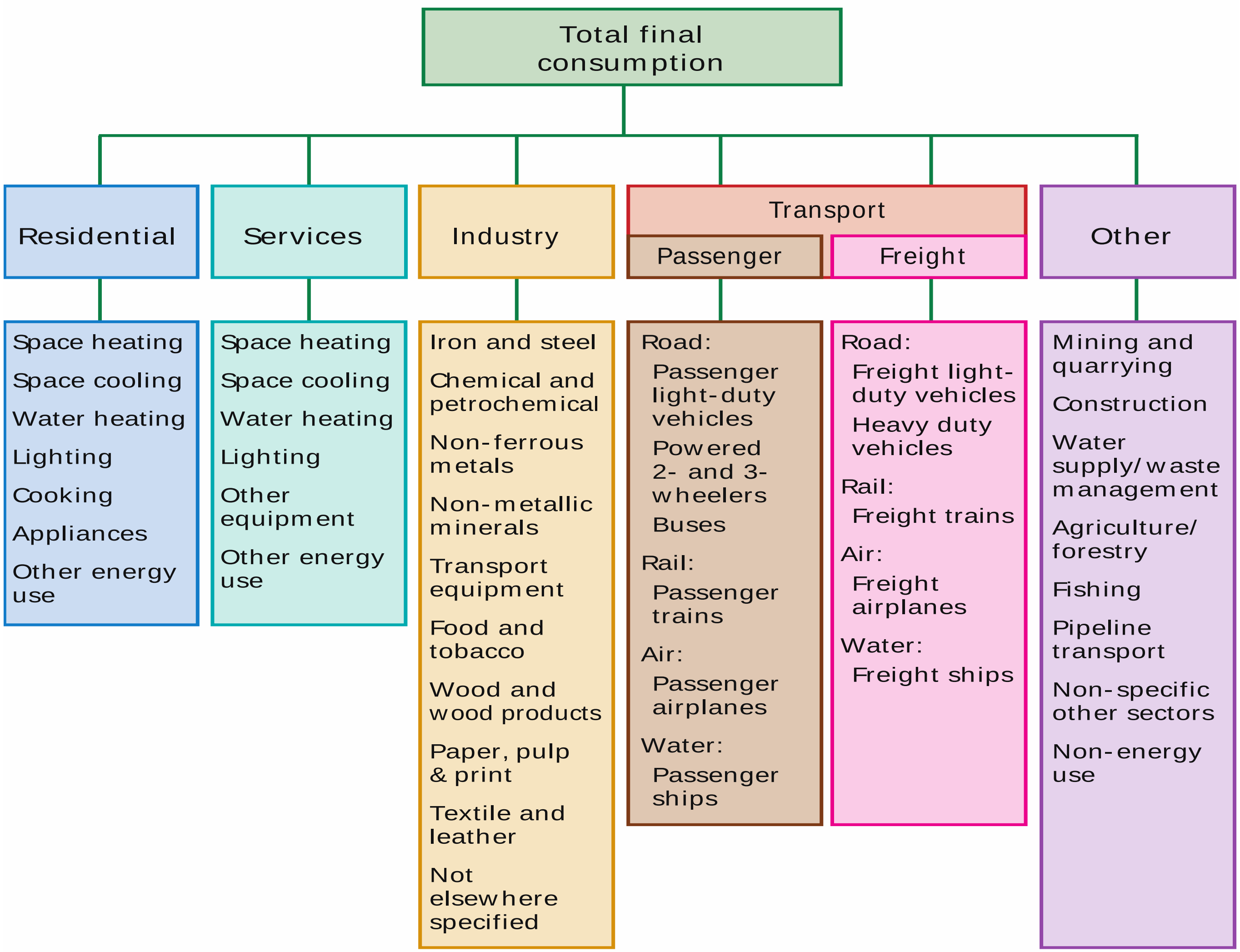
Schematic representation of energy indicators



Source: IEA, 2019

Energy Demand Analysis

Disaggregation of total final energy consumption into sectors



Source: IEA, 2014

Household energy demand

- The microeconomic basis for consumer energy demand relies on consumers' utility maximization principles. Such an analysis assumes that consumers know their preference sets and ordering of preferences.
- It also assumes that preference ordering can be represented by some utility function and that the consumer is a rational one in that she will always choose a most preferred bundle from the set of feasible alternatives.
- Following consumer theory, it is considered that an incremental increase in consumption of a good keeping consumption of other goods constant, increases the satisfaction level but this marginal utility (or increment) decreases as the quantity of consumption increases.

Industrial and commercial energy demand

- Energy is used as an input to produce an output. The theory of the producers is used to determine energy demand in both sectors. Producers face certain constraints:

  a) The production process has its own technical limitations that specify the maximum output levels for a given combination of inputs.

  b) The capacity of the plant at any given time is fixed and cannot be exceeded.

  c) There may be constraints on the availability of certain inputs.

- Production of any good is expanded until an additional increment of the good produced in the most efficient manner makes no further contribution to net revenue. Similarly, any factor of production will be increased until, other inputs remaining unchanged, an additional unit of the factor yields no additional net revenue.

- In order to minimize the cost of any given level of input, the firm should produce at that point for which the rate of technical substitution is equal to the ratio of the inputs' rental prices.

Transport energy demand

- For energy demand in the transport sector, three types of generic approaches are found: a) identity models, b) structural models and c) the market-share model.
- The identity models consider the demand for a transport fuel to be equal to the product of vehicle utilization rate, total stock of vehicles, and unit energy consumption (L/km).
- The structural model on the other hand considers the demand for the transport services and derives the demand for energy related to those transport services as a derived demand.
- The market-share model on the other hand considers the inter-fuel substitution possibilities. To ensure a consistent outcome, the demand is estimated using a set of simultaneous equation systems.

Topdown

Three main factors affect yearly changes in final energy use

- ✓ *Activity effects:* whether factors that drive energy-using activities, such as industry value-added, tonne or passenger kilometres travelled and population, increased or decreased, many of which are linked to changes in economic output.
- ✓ *Structural effects*: whether there were changes in the type of energy-using activities, such as the share of activity across various economic sectors, appliance ownership, number of buildings and floor area, and the share of different transport modes.
- ✓ *Efficiency effects*: whether the energy used per unit of activity increased or decreased.

Source: IEA, 2016

Decomposition to analyse energy efficiency

Table 1.1 Sectors and indicators included in the IEA decomposition analysis

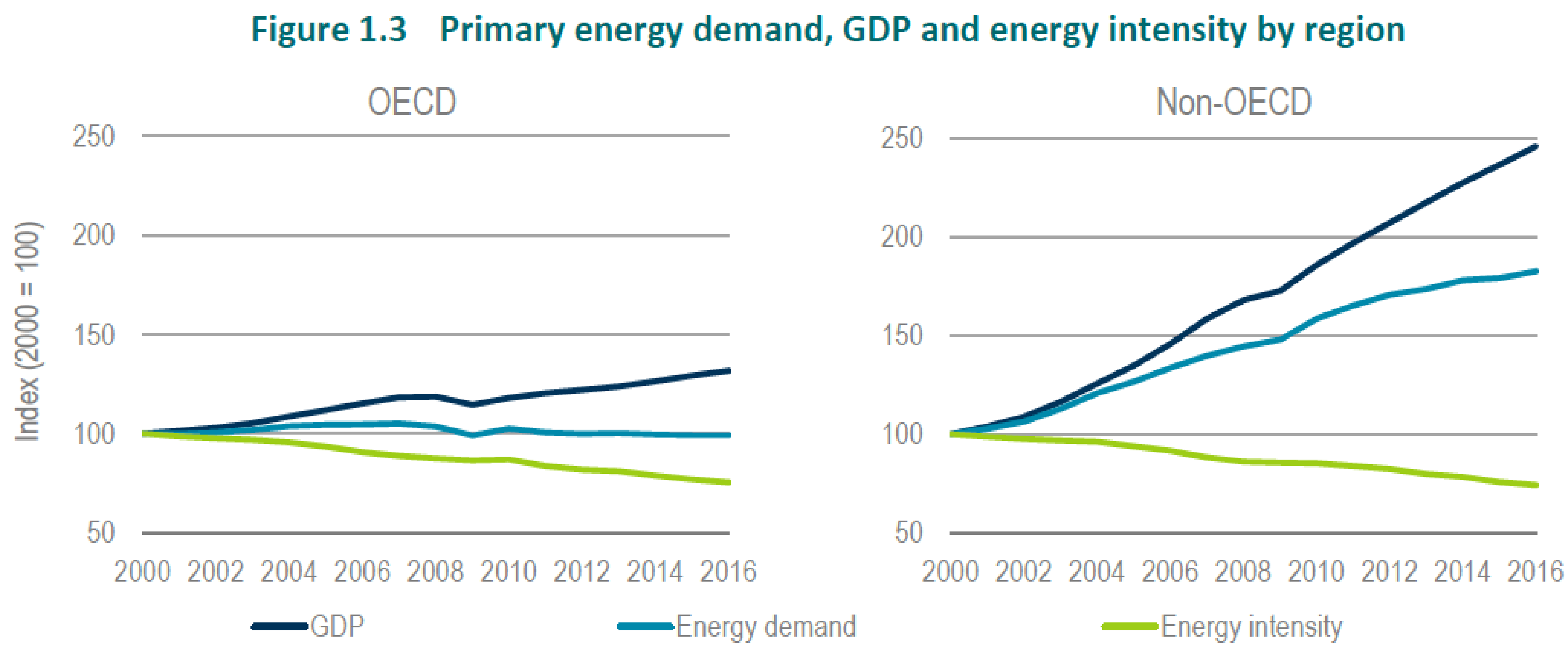
Sector	Service/sub-sector	Activity	Structure	Efficiency effect
Residential	Space heating	Population	Floor area/ population	Space heating energy*/ floor area
	Water heating	Population	Occupied dwellings/ population	Water heating energy/occupied dwellings
	Cooking	Population	Occupied dwellings/ population	Cooking energy/ occupied dwellings
	Space cooling	Population	Floor area/ population	Space cooling energy*/floor area
	Lighting	Population	Floor area/ population	Lighting energy/floor area
	Appliances	Population	Appliance stock/ population	Appliances energy/ appliance stock
Passenger transport	Car; bus; rail; domestic aviation	Passenger kilometre	Share of passenger kilometres by mode and persons per vehicle	Energy/vehicle kilometre
Freight transport	Truck; rail; domestic shipping	Tonne kilometre	Share of tonne kilometres by mode and tonnes per vehicle	Energy/vehicle kilometre
Manufacturing	Food, beverages and tobacco; paper, pulp and printing; chemicals; non-metallic minerals; primary metals; metal products and equipment; other manufacturing	Value-added	Share of value added	Energy/value-added
Services	Services	Value-added	Share of value added	Energy/value-added
Other industries**	Agriculture and fishing; construction	Value-added	Share of value added	Energy/value-added

* Adjusted for climate variation using heating degree-days.

** Because they are energy producing sectors and outside the scope of this analysis, the following sectors are not included: mining and quarrying; fuel processing; and electricity, gas and water supply. 'Other industries' are analysed only to a very limited extent.

Source: IEA, 2016

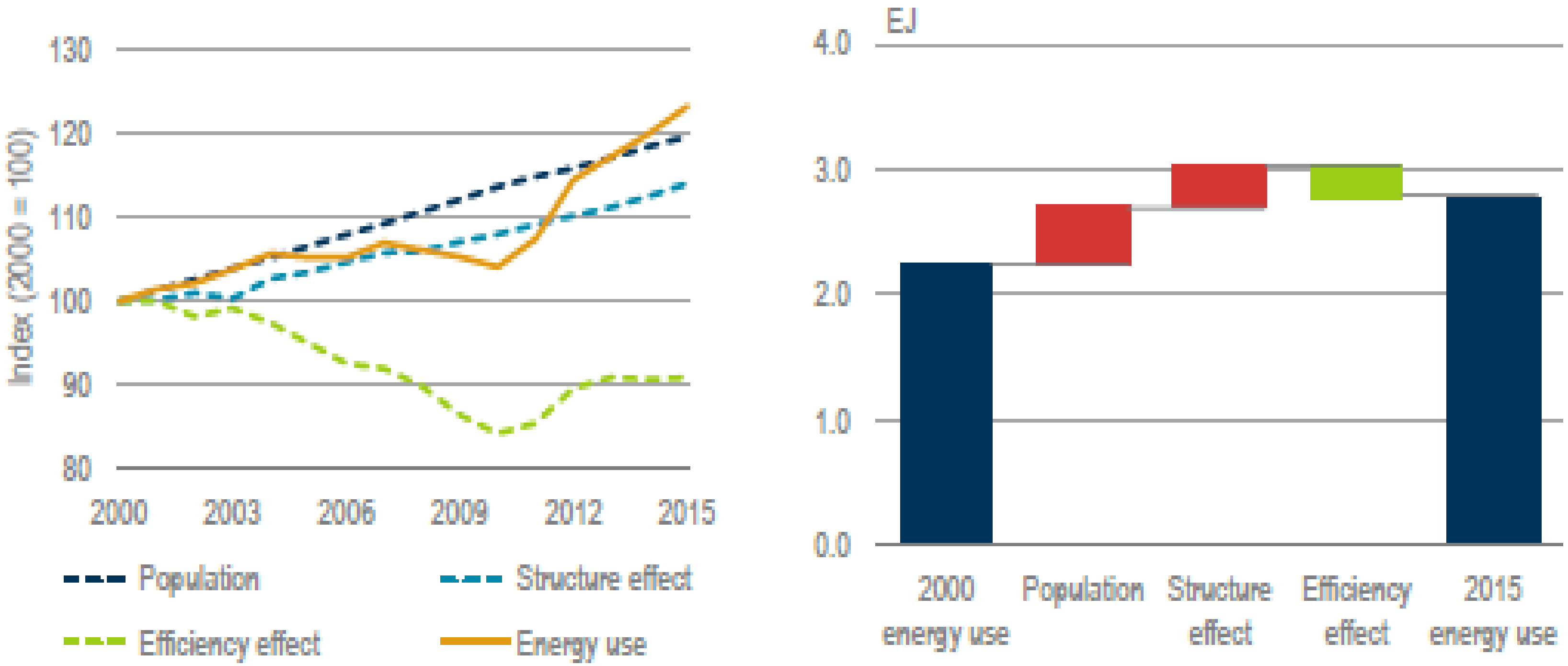
Energy demand, GDP and energy intensity



Sources: Adapted from IEA (2016a) *World Energy Outlook 2016*; and IEA (2017a), *World Energy Statistics and Balances 2017* (database), www.iea.org/statistics.

Source: IEA, 2017

Figure 5.2 Decomposition of Indonesian residential sector final energy use, 2000-15

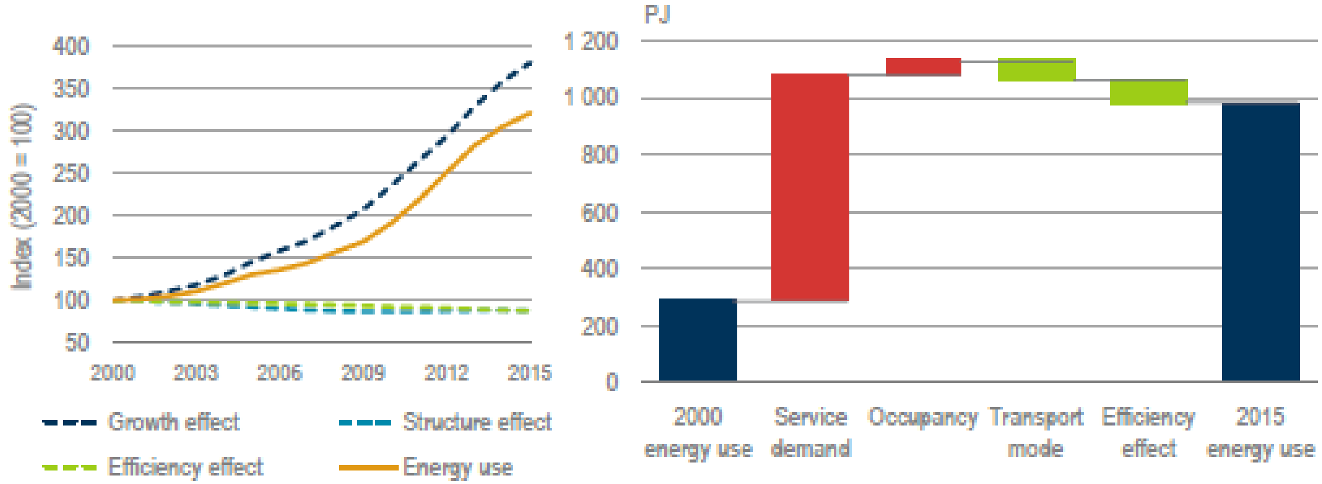


Note: Structure effect includes number of dwellings, residential floor area and appliance ownership per capita.

Source: Adapted from IEA (2017a), *Energy Efficiency Indicators* (database), www.iea.org/statistics/topics/energyefficiency/.

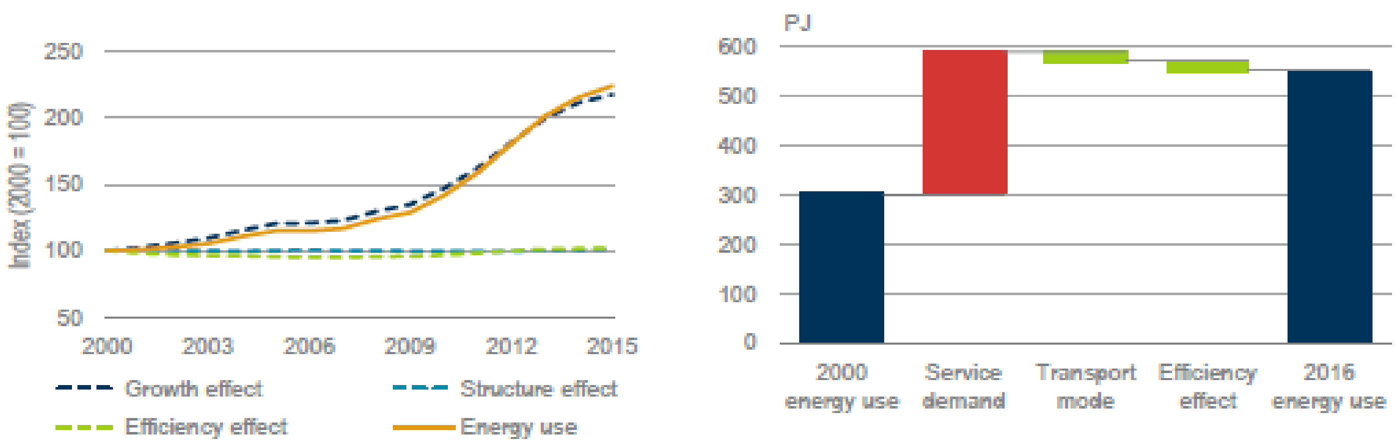
Source: IEA, 2017

Figure 5.7 Decomposition of Indonesian passenger transport final energy use, 2000-15



Source: Adapted from IEA (2017a), *Energy Efficiency Indicators* (database), www.iea.org/statistics/topics/energyefficiency/.

Figure 5.8 Decomposition of Indonesian freight transport final energy use, 2000-15



Source: Adapted from IEA (2017a), *Energy Efficiency Indicators* (database), www.iea.org/statistics/topics/energyefficiency/.

Source: IEA, 2017

Energy demand forcasting

Energy demand forecasting models

- Econometric models. Projections based on price and income factors and their relationship to energy demand - *elasticity*
- End-use models is (engineering oriented). Projections based on the technological structure of energy consumption and relate the energy consumption to factors describing the level of economic activity in each sector (drivers) – *intensity, SEC*

Econometric models

Consumption Theory

$$C = b_0 + b_1 \cdot Y_d + u$$

C: consumer's expenditure X
Y_d: consumer's disposable (after-tax) income
b_0, b_1: unknown parameters
u: random disturbance or error

Consumer Demand Theory

$$D_X = b_0 + b_1 \cdot P_X + b_2 \cdot Y + b_3 \cdot P_Z + u$$

D_x: quantity demanded of the commodity X
P_x: price of the commodity X
Y: consumer's disposable (i.e. after tax) income
P_Z: price of another (related) commodity Z

Based on the COBB-DOUGLAS production function:

$$E = a\frac{Y^{\alpha}}{P^{\beta}}$$

E: Energy Demand
Y: Income (GDP per capita)
P: Energy Price
a: coefficient

α: Income Elasticity of Energy Demand

$$\alpha = \frac{\Delta E / E}{\Delta Y / Y} = \frac{\%\ change\ in\ E}{\%\ change\ in\ Y}$$

β: Price Elasticity of Energy Demand

$$\beta = \frac{\Delta E / E}{\Delta P / P} = \frac{\%\ change\ in\ E}{\%\ change\ in\ P}$$

Typical examples of single equation econometric models

The following equations provide examples of specifications used in simple econometric analyses. E is energy consumption, Y is income (GDP), P is price, POP is population, EMP is employment of labour, a, b, c, d, e, f, - are coefficients to be determined through the estimation process, t is time period t while t-1 represents the time period before t.

(a) Linear relation between energy and income (GDP)

$E_t = a + bY_t$

This implies an (income) elasticity that tends asymptotically to unity as income increases. Note that b is not the elasticity in this specification, which has to be determined from the basic definition of elasticity.[21]

(b) Log-linear specification of income and energy

$\ln E_t = \ln a + b \ln Y_t$

Here b represents the elasticity of demand, which is a constant by specification.

(c) Linear relation between energy and price and income variables

$E_t = a + bY_t + cP_t$

This is not a popular specification however.

(d) Log-linear specification of income, price and energy

$\ln E_t = \ln a + b \ln Y_t + c \ln P_t$

As with model (b), the short-run price and income elasticities are directly obtained here.

(e) Dynamic version of log-linear specification of energy with price and income variables

End-use (engineering) model

Energy Demand for each activity results from the product of two factors: *LEVEL OF ACTIVITY* (energy service) and *ENERGY INTENSITY* (energy use per unit of service)

$$Energy\ use = \sum_{i=1}^{n} Q_i \cdot I_i$$

Q_i: Quantity of energy service i

I_i: Intensity of energy use for energy service i

$$Q_i = N_i \cdot P_i \cdot M_i$$

N_i: Number of eligible customers for end-use i

P_i: Penetration (total units/total customers) of end-use service i (can be >100%)

M_i: Magnitude of extent of end-use service i

Thank You