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Abstract

Though energy efficiency is traditionally defined in terms of two basically reciprocal indicators, as energy intensity (energy use per unit of activity output), and as energy productivity (activity output per unit of energy input), the concept is a context-specific one, not necessarily equivalent to energy savings, and is usually defined as net benefits (useful output) per unit of energy use, but without an unequivocal operationally useful quantitative measure. This necessitates construction of a series of indicators specific to the context (or level of sectoral disaggregation). It is generally believed that energy consumption is essentially determined by three effects, viz., activity, referring to economic or human activity level (output/income produced, population/households supported, passenger-km travelled, etc), structure referring to the composition of activity (shares of different sectors or subsectors of human/economic activities) and energy intensity, the quantum of energy required to deliver one unit of economic/human activity. The exact definitions and units of these factors are in turn determined by the level of aggregation. The present paper documents the definitions and units of these three effects.

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Economic Concept of Energy Efficiency

1 Energy Efficiency Indicators

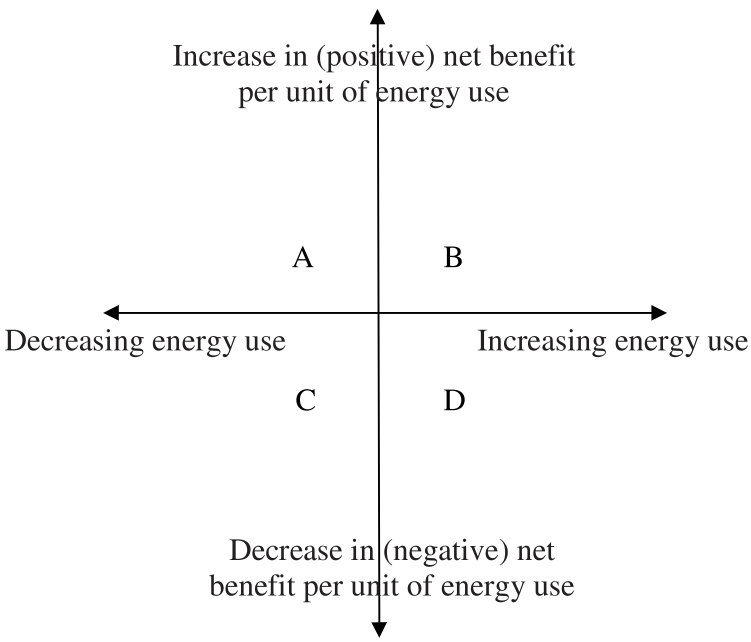
Traditionally, there are two basically reciprocal Energy Efficiency Indicators: one, in terms of energy intensity, that is, energy use per unit of activity output, and the other, in terms of energy productivity, that is, activity output per unit of energy use. As a general concept, "energy efficiency refers to using less energy to produce the same amount of services or useful output. For example, in the industrial sector, energy efficiency can be measured by the amount of energy required to produce a tonne of product." (Patterson, 1996: 377). Thus Patterson defines energy efficiency broadly by the simple ratio of the useful output of a process in terms of any good produced that is enumerated in market process, to energy input into that process (ibid.).

Defining energy efficiency in this sense (of useful output per unit of input) also helps us to define energy efficiency as "a change to energy use that results in an increase in net benefits per unit of energy" (section 3 of the Energy Efficiency and Conservation Act 2000 of New Zealand), where net benefits represent useful output.

2 Differentiating between Energy Efficiency and Energy Conservation

The concept of energy efficiency thus defined also clarifies the differences among the concepts of energy efficiency, energy conservation and energy saving. These differences may be better explained using Figure 1. The quadrants A and B represent energy efficiency, defined in terms of net benefits per unit of input. They also capture the idea of energy efficiency improvement, "defined [by Energy Efficiency and Conservation Authority, 1997] as any change in energy use that results in increased net benefits per unit of energy, whether or not total energy use increases or decreases" (Lermit and Jollands (2001, p. 7). Thus, quadrant B represents energy efficiency improvement, by increasing net benefits per unit of energy use through increasing energy use and quadrant A, on the other hand, represents energy efficiency improvement, by increasing net benefits per unit of energy use through decreasing energy use (for example, by installing double-glazing windows that can reduce heating energy bill costs during winter).

Figure 1: The energy efficiency and conservation quadrants



Source: Adapted from Lermit and Jollands (2001, p. 7).

Cases like quadrant B simply show that energy efficiency improvement need not imply energy savings and render monitoring energy efficiency difficult. "If energy efficiency were the same as energy savings, then all that would be required would be to estimate the amount of energy saved compared to some base year and add up energy savings across sectors. However, this does not necessarily equate to energy efficiency." (Lermit and Jollands (2001, p. 8).

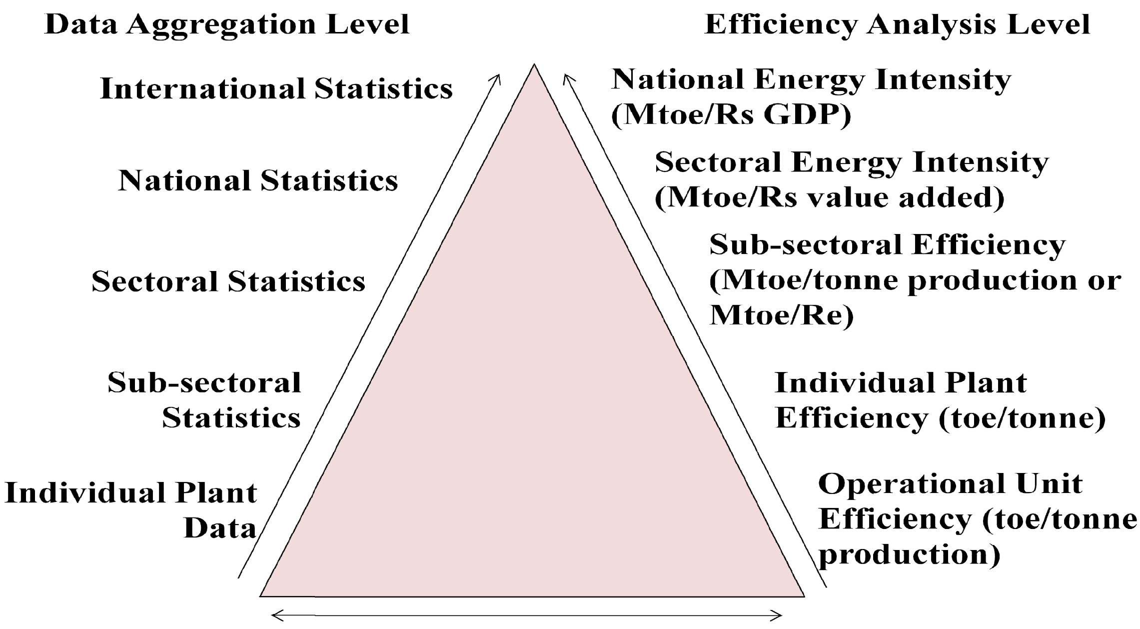
Energy conservation, as an important complement to energy efficiency, is defined in terms of reduction in total energy use, and is thus represented by quadrants A and C. Thus, this can happen in two ways: quadrant A represents efficiency-improving energy conservation, where energy savings lead to an increase in net benefits per unit of energy use; and quadrant C represents efficiency-reducing energy conservation, where energy savings lead to a decrease in net benefits per unit of energy use, "as is the case with the proverbial "cold bath in the dark"" (ibid.).

In short, the above discussion reminds us that energy efficiency is a context-specific concept, not necessarily equivalent to energy savings, and is usually defined as net benefits (useful output) per unit of energy input, but without an unequivocal operationally useful quantitative measure. This necessitates construction of a series of indicators specific to the context (or level of sectoral disaggregation, as discussed below).

3 Energy Efficiency Indicators at Different Aggregation Levels

It is possible to design and devise energy efficiency indicators at different levels of aggregation, using the corresponding statistics. Thus at the highest level of aggregation, we can use the international statistics for national level indicators, and from there we can come down to different disaggregated levels of a national economy; for instance, using national economic statistics, we can have various macro-sectoral indicators, and coming down to the most disaggregated micro level data on individual plant, we can construct energy efficiency indicators of the corresponding operational units. This is illustrated in Figure 1 below in a pyramid framework.

Figure 2: Energy Efficiency Indicator Pyramid



Quantity of data required

Note: Mtoe = Million tonnes of oil equivalent; toe = the tonne of oil equivalent = a unit of energy = the amount of energy released by burning one tonne of crude oil; approximately 42 gigajoules or 11,630 kilowatt hours.

As we know, higher levels of aggregation conceal many relationships and effects, functioning at the micro levels. As we move down the pyramid to micro levels, these relationships and effects appear more clearly, providing better understanding of the ground reality that throws more light on the macro-level reality. However, the quantity and quality of data required at the bottom of the pyramid increases substantially, and the data availability becomes more and more difficult.

4 Determinants of Energy Efficiency Indicators

It is generally believed (for example, Schipper, et al., 1992; Phylipsen et al., 1998) that energy consumption is essentially determined by the following effects:

(i) Activity (Ai) – economic or human activity level (output/income produced, population/households supported, passenger-km travelled, etc)

(ii) Structure (Si) – the composition of activity (shares of different sectors or subsectors of human/economic activities)

(iii) Energy intensity (Ii =Ei/Ai) – quantum of energy required to deliver one unit of economic/human activity.

Thus the total energy consumption across all the sectors

$$E = \sum_i E_i = \sum_i A \frac{A_i}{A}\frac{E_i}{A_i} = \sum_i A\, S_i I_i$$

where E is the total energy consumption, A (= $\sum_i A_i$) is the activity level, S_i (= S_i /S) is the ith sector's activity share and I_i (= E_i /A_i) is that sector's energy intensity.

Recent contributions have included two additional parameters; climate and behaviour. However, in practice, we can find that they are only part of the basic factors given above, as climate is a structural factor, for example, for heating applications, and behaviour is a part of energy intensity.

The level of aggregation, as outlined above in the pyramid structure, determines the exact definitions and units of these factors. Thus at the highest aggregation level of the macro economy, the activity is measured in economic terms (GDP or value-added, VA), and hence energy intensity, in terms of energy consumption (Giga Joule per unit of GDP (GJ/GDP) or per unit of value-added (GJ/VA); similarly, structure is defined as the share of the different sectors (primary, secondary and tertiary). At a lower level of aggregation, for instance, the steel industry within the industry sector, activity may be measured in either value-added or tonnes of steel produced, energy intensity in either GJ/VA or GJ/tonne steel, and structure in terms of the share of primary and secondary steel in total or in some other shares.

A detailed illustration of this for the bottom micro-level sectors is given in Table 1 below. For example, the residential or domestic sector consists of a number of subsectors such as space heating/cooling, water heating, cooking, lighting, appliances, etc. Activity in each subsector is measured in terms of the corresponding population or number of households, structure in the case of space heating/cooling and lighting is defined in terms of floor area per capita and intensity in terms of energy per square feet floor area. In transport sector, passenger and freight transport are the two subsectors, with passenger-km and ton-km as respective activities. The other two factors are similarly defined. Both in services and manufacturing, value-added measures the activity with corresponding shares and intensity factors.

Table 1: Micro-level Determinants of Energy Efficiency Indicators

Sector (i)	Subsector (j)	Activity (Aj)	Structure (Sj)	Intensity (Ij = Ej/Aj)
Residential or domestic	Space heating/cooling	Population, Number of Households and Floor area (sq. ft.)	Floor area/capita	Energy/floor area
	Water heating		Person/HH	Energy/capita
	Cooking		Person/HH	Energy/capita
	Lighting		Floor area/capita	Energy/floor area
	Appliances		Ownership/capita	Energy/appliance
Transport	Passenger	Passenger-km	Share in total Passenger-km	Energy per passenger-km
	Car Bus Rail Domestic air			
	Freight	Ton-km	Share in total Ton-km	Energy per Ton-km
	Trucking Pipelines (Natural gas Petroleum) Air Water			
Services	Any sector	Value-added	Share in total VA	Energy/VA
Manufacturing	Any sector	Value-added	Share in total VA	Energy/VA

Source: Adapted from Schipper, et al. 2001; and https://www.energy.gov/sites/prod/files/2015/06/f24/index_methodology.pdf

A number of different formulations are used to generate energy efficiency indicators such as those given in the Table 2 below.

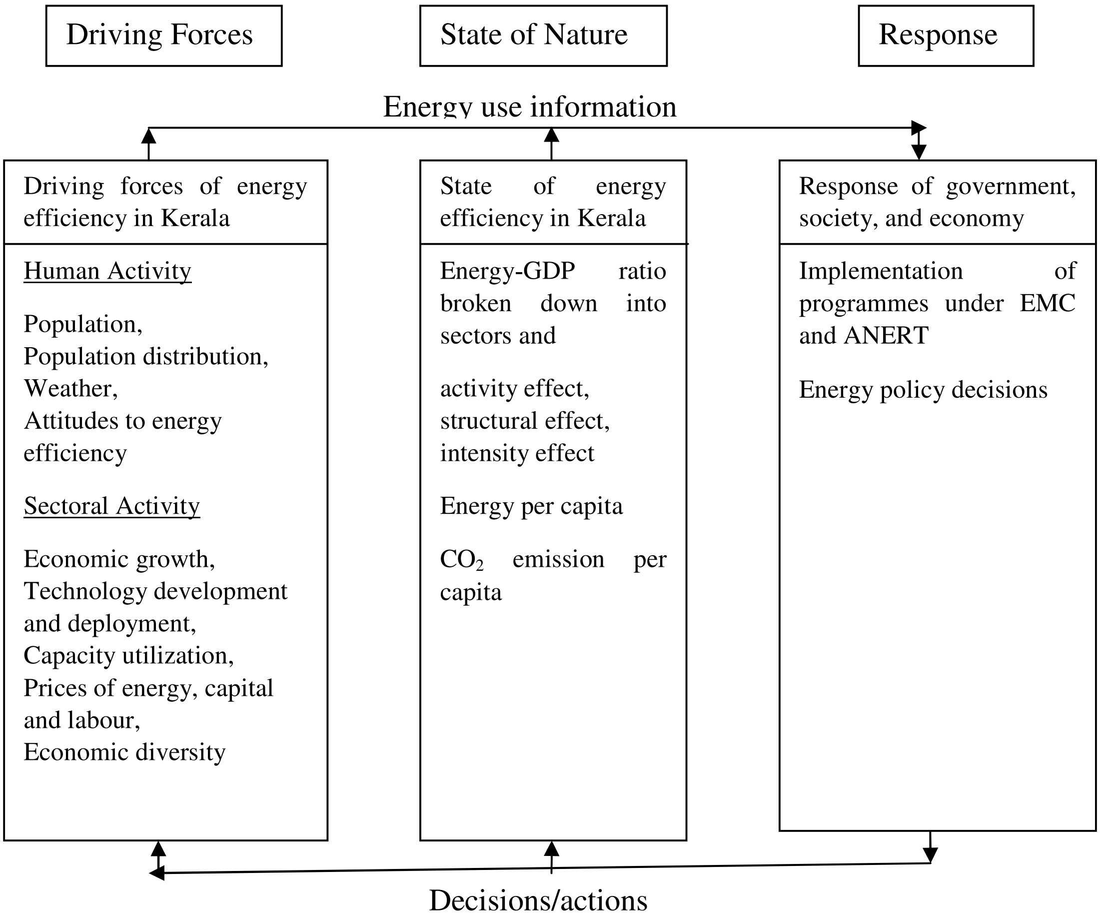
Table 2: Determinants of Energy Efficiency Indicators

Aggregation level	Indicator	Combines effects of	The indicator can assess	The indicator cannot assess
Economy as a whole	Energy per GDP	Share of different sector and subsectors, energy intensity of each of the (sub-) sectors, costs of the production factors (energy, material, labour) and value of products and services delivered, share of sectors that do not generate (account for) value	Energy required to produce an amount of GDP	Energy efficiency, level of development, future trends, improvement potentials
Sectoral intensity				
Industry	Energy per VA	Share of different types of subsectors, energy intensity of each of the sub-sectors, costs of the production factors (energy, material, labor) and value of products delivered	Final energy required to produce an amount of VA in this sector	Share of primary resources to generate VA; Future trend in energy consumption; Energy efficiency; Improvement potential
Residential	Energy per capita	Dwelling size (square feet/house), household size (number of people/house), type of dwellings, number of appliances, usage of appliances (number of hours), climate, efficiency of dwelling and appliances, behaviour		Energy required for a certain level of welfare or services provided; Energy efficiency; Energy efficiency improvement potential
Transport	Energy per passenger-km or per ton-km	Share of passenger transport and freight transport, share of various modes (car, bus, truck, train, boat, plane), occupancy load (number of passengers or ton per vehicle), distance travelled by each of the modes, energy intensity of each of the modes		

Source: Adapted from G.J.M. Phylipsen, Energy Efficiency Indicators: Best practice and potential use in developing country policy making. 30 June 2010 Phylipsen Climate Change Consulting, Commissioned by the World Bank. P. 19.

5 A Conceptual Framework for Energy Efficiency in Kerala

A conceptual framework for monitoring energy efficiency of Kerala may be summarized as follows:



Source: Adapted from Lermit and Jollands (2001, p. 17).

References

Lermit, J. and Jollands, N. (2001) *Monitoring Energy Efficiency Performance in New Zealand: A Conceptual and Methodological Framework*, National Energy Efficiency and Conservation Authority, Wellington.

Patterson M. G., (1993). 'An accounting framework for decomposing the energy-to-GDP ratio into its structural components of change', *Energy*, Volume 18, Issue 7, July, Pages 741-761.

Phylipsen, G.J.M. (2010) Energy Efficiency Indicators: Best practice and potential use in developing country policy making. 30 June Phylipsen Climate Change Consulting, Commissioned by the World Bank.

Phylipsen, G.J.M., K. Blok and E. Worrell, (1998), *Handbook on International Comparisons of Energy Efficiency in the Manufacturing Industry,* commissioned by the Ministry of Housing, Physical Planning and the Environment, Dept. of Science, Technology and Society, Utrecht University, Utrecht, 1998.

Schipper, Lee; Unander, Fridtjof; Murtishaw, Scott and Ting, Mike (2001) *Annual Review of Energy and the Environment* Vol. 26:49-81 (Volume publication date November https://doi.org/10.1146/annurev.energy.26.1.49

Schipper, L.J., Meyers, S., Howarth, R., and Steiner, R., (1992), *Energy Efficiency and Human Activity: Past Trends, Future Prospects,* Cambridge Studies in Energy and the Environment, ed. C. Hope and J. Skea. Cambridge University Press, Cambridge, UK (1992).