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Assessing Energy Consumption and Energy Intensity Changes in Pakistan: An Application of Complete Decomposition Model

SHAISTA ALAM and MOHAMMAD SABIHUDDIN BUTT

Complete decomposition model has been employed in the present study to decompose the changes in energy consumption and energy intensity in Pakistan during 1960 to 1998. A general decomposition model raises a problem due to residual term. In some models the residual term is omitted, which causes a large estimation error, while in some models the residual term is regarded as an interaction that might create a puzzle for the analysis. A complete decomposition model is used here to solve this problem.

1. INTRODUCTION

The national economy could be disaggregated into two groups—one group consists of low energy-intensive sectors and the other consists of high energy-intensive sectors.[1] If decomposition model applies at this level, it is called single-level decomposition, or decomposition at level one, or decomposition at groups level. If each group could be further disaggregated into several sectors, then decomposition at sector level would be attributed to decomposition at level two (see Chart 1). If decomposition is carried out at more than one level, it is to be called a multilevel decomposition. For the present analysis, only a single-level decomposition model is used to estimate the changes in energy consumption and changes in energy intensity in Pakistan.

Actually, the decomposition models lead to an approximate decomposition. These kinds of decomposition methods have been proposed by [Hankinson and Rhys (1983); Reitler, *et al.* (1987); Boyd, *et al.* (1988); Doblin and Claire (1988); Howarth (1991); Howarth and Schipper (1992); Park (1992); Park, *et al.* (1993), etc. The

Shaista Alam and Mohammad Sabihuddin Butt are Research Assistant and Senior Research Economist respectively at Applied Economics Research Centre, University of Karachi.

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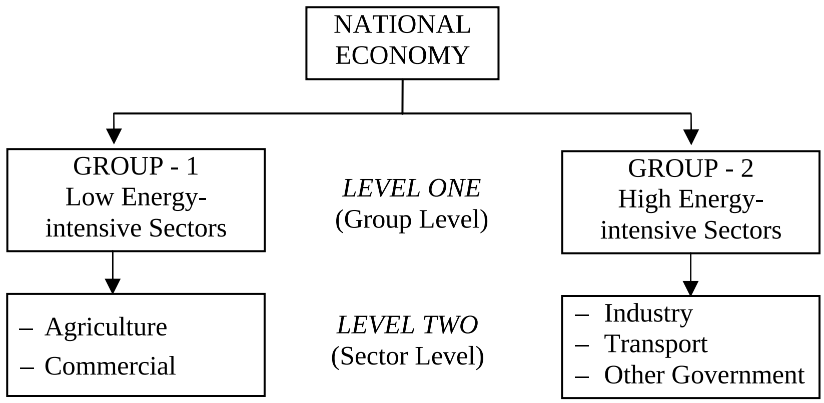
[1]On the basis of intensity used, the agriculture and commercial sectors are low energy-intensive sectors and transport, industry, and other government sectors are high energy-intensive sectors.

Chart 1

DISAGGREGATION OF THE ECONOMY
AT
VARIOUS LEVELS



main imperfection of these methods is the residual term. The residual term in most studies was omitted [Hankinson and Rhys (1983); Reitler, *et al.* (1987); Boyd, *et al*. (1988); Doblin and Claire (1988); Howarth (1991); Howarth and Schipper (1992)] and in some studies was called the interaction of effects [Park (1992); Park, *et al.* (1993)]. The omitted residual causes a large estimation error, and is regarded as an interaction that might create a puzzle for the analysis. The purpose of employing the complete decomposition model (CDM) is to improve the reliability and accuracy of the analytical model [Sun (1996)].

The aim of the study is to decompose the changes in energy consumption and the changes in energy intensity in Pakistan during the period 1960–1998. The change in energy consumption is decomposed into the scale of economic activity (the activity effect), the sectoral technological level (the intensity effect), and the economic structure (the structural effect). While the change of energy intensity is decomposed into sectoral energy intensity effect and sectoral structural effect [Sun (1998)], the purpose of employing complete decomposition model is to decompose the change of energy use in Pakistan and to quantify the contribution of each effect on different energy intensive groups in terms of the change of energy consumption and the change of energy intensity in Pakistan during the period under consideration. In this study, economy is divided into two groups—Group-1 consists of low energy-intensive sectors and Group-2 consists of high energy-intensive sectors.

Several studies in energy economics have employed the technique of decomposition to examine the changes of energy consumption and changes of energy intensity. The studies by Liu, *et al.* (1992) and Ang and Lee (1994) deal with a decomposition technique that we shall refer to as the energy consumption approach, i.e., decomposition over time into contributions from changes in aggregate production (production effect), production structure (structural effect), and sectoral energy intensities (intensity effect). Several analysts have proposed a method using the energy intensity approach, where decomposition is carried out on changes in aggregate energy intensity.[2] In the energy intensity approach, changes in aggregate intensity are decomposed into contributions from structural and intensity effects only. Examples of such studies are Jenne and Cattell (1983) and Bending, *et al.* (1991). The energy intensity approach has been used in a large number of empirical and country-specific studies [Bossanyi, (1979); Jenne and Cattell (1983); Ang (1994); Li, *et al.* (1990); Gardner (1993); Huang (1993)].

2. METHODOLOGY: COMPLETE DECOMPOSITION MODEL (CDM)[3]

To study the impact of structural changes (i.e., shifts in the composition of total output) and energy consumption on aggregate energy efficiency improvement, the national energy intensity will be decomposed with the help of the complete decomposition model (CDM). The general decomposition model leads to an approximate decomposition because it has a residual term. The residual influences the accuracy of the model. In some studies the residual was omitted and this caused a large estimation error; the residual was regarded as an interaction that still leaves a new puzzle for analysis. The complete decomposition model has solved this problem. The complete decomposition model for explaining the relationship between energy consumption and the change of the energy intensity could be written as follows:

2.1. The Energy Intensity Model (EIM)

Aggregate energy intensity: $I^t = \sum_i I_i^t S_i^t$ … … … (1)

Change in aggregate energy intensity: $\Delta I = I^t - I^o$ … … (2)

where,

I^t = Aggregate energy intensity in year t ($I^t = E^t / Y^t$).

S_i^t = Output share of group i (where i=1,2) in GDP in year t ($S_i^t = Y_i^t / Y^t$).

I_i^t = Energy intensity of group i (where i=1,2) in year t ($I_i^t = E_i^t / Y_i^t$).

[2]Aggregate energy intensity is defined as the ratio of total energy consumption to total output.

[3]We have largely drawn on Sun (1998) in this section.

The changes in aggregate energy intensity are attributed to the sectoral energy intensity effect (II_{effect}) and to the sectoral structural effect (IS_{effect}). Therefore, the decomposition model for the change in energy intensity would be:

$$\Delta I = II_{\text{effect}} + IS_{\text{effect}} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (3)$$

where,

$$II_{\text{effect}} = \sum_i S_i^o \Delta I_i + \frac{1}{2}\sum_i \Delta I_i \Delta S_i \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (4)$$

$$IS_{\text{effect}} = \sum_i I_i^o \Delta S_i + \frac{1}{2}\sum_i \Delta S_i \Delta I_i \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (5)$$

Thus contribution of the change of group i (where i=1,2) to the total change of energy intensity would be:

$$I_{\text{group}\,i} = S_i^o \Delta I_i + I_i^o \Delta S_i + \Delta I_i \Delta S_i \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (6)$$

The first term of the above equation indicates the contribution of change to the energy intensity of group i. The second term represents the contribution of changes in the production share of group i, while the third term indicates the interaction between both factor changes in group i.

2.2. The Energy Consumption Model (ECM)

Final energy consumption: $E^t = Y^t \sum_i I_i^t S_i^t$ … … … (7)

The change in energy consumption: $\Delta E = E^t - E^o$ … … (8)

where,

E^t = Energy consumption in year t.

E^o = Energy consumption in base year (t=0).

I_i^t = Energy intensity of group i in year t.

S_i^t = Output share of group i in year t.

Y^t = Aggregate output in year t.

Since energy consumption and the change in energy consumption are influenced by the activity effect (EY_{effect}), structural effect (ES_{effect}), and intensity effect (EI_{effect}), the decomposition model for the change in energy consumption would be:

$$\Delta E = EY_{\text{effect}} + ES_{\text{effect}} + EI_{\text{effect}} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (9)$$

This is an exact decomposition, where

$$EY_{\text{effect}} = \Delta Y \sum_i I_i^o S_i^o + \frac{1}{2}\Delta Y \sum_i (I_i^o \Delta S_i + S_i^o \Delta I_i) + \frac{1}{3}\Delta Y \sum_i \Delta I_i \Delta S_i \quad \ldots \quad (10)$$

$$ES_{\text{effect}} = Y^o \sum_i I_i^o \Delta S_i + \frac{1}{2}\sum_i \Delta S_i (I_i^o \Delta Y + Y^o \Delta I_i) + \frac{1}{3}\Delta Y \sum_i \Delta I_i \Delta S_i \ldots \quad \ldots (11)$$

$$EI_{\text{effect}} = Y^o \sum_i S_i^o \Delta I_i + \frac{1}{2}\sum_i \Delta I_i (S_i^o \Delta Y + Y^o \Delta S_i) + \frac{1}{3}\Delta Y \sum_i \Delta I_i \Delta S_i \quad \ldots \quad \ldots (12)$$

Where the first term of the above three equations represents the contribution of the change of factor Y (Production), S (Group share in total production), and I (Intensity) respectively to the total change in energy consumption. The second term represents the contribution of change of one factor with the sum of the partial changes of the other two factors with respect to group i. The third term is the residual in the general decomposition model. It could be attributed either to Y (Production), I (Intensity), or S (Group share of total production) by equal impact. That contribution is dependent on all of the three changes and if only one of them goes to zero, the other effects disappear. When there is no reason to assume the contrary, it is divided equally between Y's, I's, and S's contribution.

Y_i^o = Aggregate output in base year (t=0).

I_i^o = Intensity of gorup i (i=1,2) in base year (t=0).

S_i^o = Output share of group i (i=1,2) in base year (t=0).

ΔY = Change in aggregate output (GDP).

$\Delta Y = Y^t - Y^o$.

ΔI_i = Change in intensity of group i (where i=1,2).

$\Delta I_i = I_i^t - I_i^o$.

ΔS_i = Change in output share of group i (where i=1,2).

$\Delta S_i = S_i^t - S_i^o$.

Therefore, the contribution of the change of group i to the total change of energy consumption would be:

$$E_{\text{group } i} = I_i^o S_i^o \Delta Y + Y^o (S_i^o \Delta I_i + I_i^o \Delta S_i) + Y^o \Delta S_i \Delta I_i + I_i^o \Delta Y \Delta S_i + S_i^o \Delta Y \Delta I_i + \Delta Y \Delta I_i \Delta S_i \ldots (13)$$

The first term represents the contribution of change in *Y* (Total production). The second term indicates the sum of changes in *I* (Intensity) and *S* (Group share in production), with the other two factors at base year. The third, fourth, and fifth term represent the contribution of changes to two factors out of three, with the third factor at base year and the last term attributed to changes in all three factors.

3. DATA

The annual data of Gross Domestic Product (GDP), between 1960 and 1998, in local currency and at 1981 prices, are collected from the *Economic Survey of Pakistan* and *50 Years of Pakistan Statistics* (Federal Bureau of Statistics). Sectoral energy consumption data are compiled from *Energy Data Book* and *Energy Yearbook* (Ministry of Petroleum and Natural Resources, Government of Pakistan). All are converted into tonnes of oil equivalent.

4. EMPIRICAL FINDINGS AND DISCUSSIONS

The commercial energy consumption, GDP, and aggregate energy intensity in Pakistan for various benchmark years are reported in Table 1. The commercial energy consumption in Pakistan during the period 1960–1998 increased ninefold, which is greater than the GDP growth during the period. The aggregate energy intensity of the national economy in the same period increased by 3.9 TOE*/million rupees at 1980-81 constant price from 23.38 TOE/million rupees in 1960 to 27.28 TOE/million rupees in 1998. The energy consumption in Group-1 (low energy-intensive sectors) was increased by 1.35 MTOE** from 0.16 MTOE in 1960 to 1.51 MTOE in 1998, while in Group-2 (high energy-intensive sectors), it was increased by 14.6 MTOE, from 1.87 MTOE in 1960 to 16.47 MTOE in 1998. While GDP increased by Rs 572.4 billion, from Rs 46.5 billion in 1960 to Rs 245.7 billion in 1998 in Group-1, GDP of Group-2 increased by Rs 238 billion, from Rs 22 billion in 1960 to Rs 260 billion in 1998.

There are some interesting results about energy intensity for both groups. The energy intensity of low energy-intensive group increased approximately twofold from 1960 to 1998, while the energy intensity of high energy-intensive group decreased gradually by 25 percent of the intensity of 1960. Group-1 contributes only 8.5 percent to total change of energy consumption, while Group-2 contributes 91.5 percent during the period.

4.1. Decomposition of the Change in Energy Intensity

Table 2 reports the factor analysis of the change of energy intensity. For the total intensity change, the structural effect is found to be positive and the intensity effect is negative in all sub-periods and during the whole period (1960–1998). This implies that energy intensity increased by 9.42 TOE/million rupees due to the

* Tonnes of oil equivalent.
** Million tonnes of oil equivalent.

Table 1

Final Energy Consumption, GDP, and Energy Intensity in Pakistan

	1960	1960–70	1970	1970–80	1980	1980–90	1990	1990–98	1998
					Pakistan				
EC	2.02	2.18	4.20	2.73	6.93	6.30	13.23	4.75	17.98
GDP	86.60	77.40	164.00	97.00	261.00	213.00	474.00	185.00	659.00
I	23.38	2.24	25.61	0.93	26.54	1.36	27.90	–0.62	27.28
					Low Energy-intensive Sectors (Group-1)				
EC	0.16	0.20	0.36	0.30	0.66	.050	1.16	0.34	1.51
GDP	46.49	33.17	79.67	28.98	108.64	70.14	178.78	66.90	245.68
I	3.34	1.18	4.52	1.58	6.10	0.41	6.51	–0.38	6.13
					High Energy-intensive Sectors (Group-2)				
EC	1.87	1.97	3.84	2.42	6.26	5.80	12.06	4.41	16.47
GDP	22.15	26.06	48.21	42.56	90.77	88.04	178.81	81.08	259.99
I	84.37	–4.71	79.66	–10.65	69.02	–1.55	67.47	–4.10	63.36

Source: Pakistan Economic Survey and *Pakistan Energy Yearbook.*

Unit: Energy consumption in million TOE, GDP in billions Rs 1980-81, and energy intensity in TOE/million Rs.

Table 2

Factor Analysis of the Change of Energy Intensity

Time Period	Contribution to the Total Change by: Structural Effect	Contribution to the Total Change by: Intensity Effect	Total Change
1960–1970	2.93 (130.80%)	–0.69 (–30.80%)	2.24 (100.00%)
1970–1980	3.63 (390.32%)	–2.70 (–290.32%)	0.93 (100.00%)
1980–1990	1.76 (128.47%)	–0.39 (–28.47%)	1.37 (100.00%)
1990–1998	1.10 (–174.60%)	–1.73 (274.60%)	–0.63 (100.00%)
1960–1998	9.42 (240.92%)	–5.51 (–140.92%)	3.91 (100.00%)

Unit: TOE /million Rs.

structural effect and decreased by 5.51 TOE/million rupees due to the intensity effect during the period under consideration. As a result, the increase in aggregate intensity was 3.91 TOE/million rupees in the same period. The results indicate that the increase in aggregate energy intensity was due mainly to the structural effect because, in Pakistan, the structural changes appeared to be significant during the same period. Consequently, it appears that aggregate energy efficiency decreased due to the structural change in the country (See Figure 1).

Contributions of groups to the total change in energy intensity are reported in Table 3. The results indicate that the high energy-intensive group (industry, transport, and other government sectors) contributes 87.5 percent change in aggregate energy intensity change, during the whole time-period considered. In all sub-periods, the high energy-intensive group shows a large change and the low energy-intensive group shows a small change in total energy intensity changes. This could be a result of improved efficiency of energy use of the relatively high energy-intensive group.

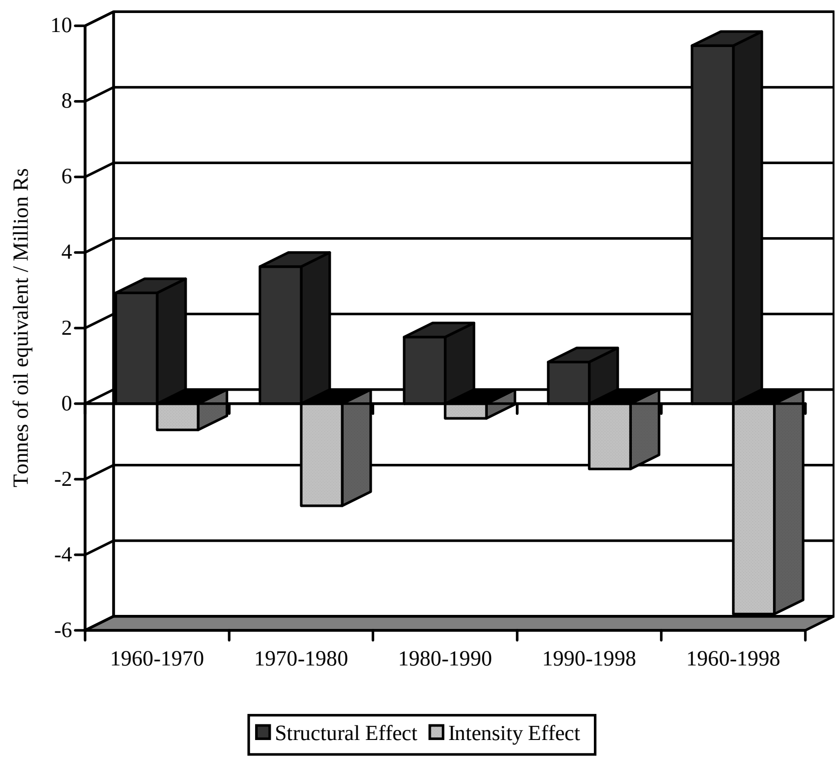


Fig. 1. Factor Analysis of the Change of Energy Intensity.

Table 3

Contribution of Groups to the Total Change in Energy Intensity

Time Period	Contribution to the Total Change by: Low Energy-intensive Group	Contribution to the Total Change by: High Energy-intensive Group	Total Change
1960–1970	0.40	1.84	2.24
	(17.86%)	(82.14%)	(100.00%)
1970–1980	0.35	0.58	0.93
	(37.63%)	(62.37%)	(100.00%)
1980–1990	–0.08	1.45	1.37
	(–5.84%)	(105.84%)	(100.00%)
1990–1998	–0.18	–0.45	–0.63
	(28.57%)	(71.43%)	(100.00%)
1960–1998	0.49	3.42	3.91
	(12.53%)	(87.47%)	(100.00%)

Unit: TOE /million Rs.

4.2. Decomposition of the Change in Energy Consumption

Factor analysis for the change of energy consumption is presented in Table 4, and graphically by Figure 2. The energy consumption increased by 14.82 MTOE and 3.37 MTOE by the activity effect and the structural effect, respectively. However, the energy consumption decreased by 2.24 MTOE by the intensity effect (improvement of energy efficiency) during the period under consideration. Finally, the total energy consumption increased by 15.94 MTOE in the same period. In all sub-periods energy consumption increased by the activity effect and the structural effect while aggregate energy consumption decreased by the intensity effect, findings which also reinforce earlier results—that the structural effect appeared more pronounced for the impact of energy efficiency in the country during the period under consideration.

Contribution of groups to the total change in energy consumption is reported in Table 5. The results show that the high energy-intensive group contributes a large increase and the low energy-intensive group contributes a small increase in the total increase of aggregate energy intensity during the period under consideration. From 1960 to 1998 total increases in aggregate energy intensity were 16 percent, to which the high energy-intensive group contributes 91.6 percent and the low energy-intensive group contributes only 8.4 percent. These results reconfirm the previous findings that the high energy-intensive group is mainly responsible for improved efficiency of energy use in the country, during the period under consideration.

Table 4

Factor Analysis for the Change of Energy Consumption

Time Period	Contribution to the Total Change by Activity Effect	Structural Effect	Intensity Effect	Total Change
1960–1970	1.89 (87.10%)	0.37 (17.05%)	–0.09 (–4.15%)	2.17 (100.00%)
1970–1980	2.55 (93.75%)	0.77 (28.31%)	–0.60 (–22.06%)	2.72 (100.00%)
1980–1990	5.80 (92.06%)	0.65 (10.32%)	–0.15 (–2.38%)	6.30 (100.00%)
1990–1998	5.11 (107.58%)	0.62 (13.05%)	–0.98 (–20.63%)	4.75 (100.00%)
1960–1998	15.35 (96.30%)	2.41 (15.12%)	–1.82 (–11.42%)	15.94 (100.00%)

Unit: Million TOE.

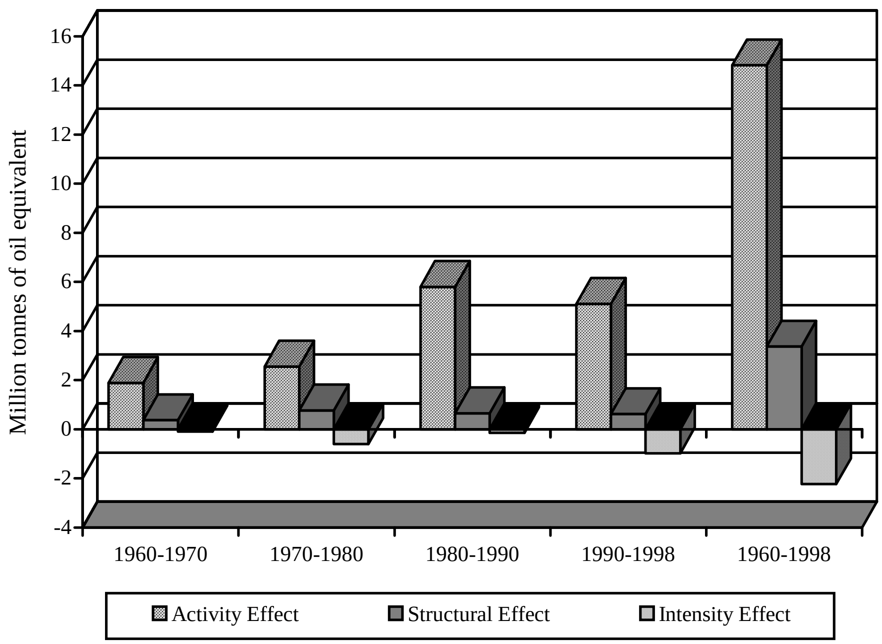


Fig. 2. Factor Analysis of the Change of Energy Consumption.

Table 5

Contribution of Groups to the Total Change in Energy Consumption

Time Period	Contribution to the Total Change by: Low Energy-intensive Group	Contribution to the Total Change by: High Energy-intensive Group	Total Change
1960–1970	0.20 (9.22%)	1.97 (90.78%)	2.17 (100.00%)
1970–1980	0.30 (11.03%)	2.42 (88.97%)	2.72 (100.00%)
1980–1990	0.50 (7.94%)	5.80 (92.06%)	6.30 (100.00%)
1990–1998	0.34 (7.16%)	4.41 (92.84%)	4.75 (100.00%)
1960–1998	1.34 (8.40%)	14.60 (91.60%)	15.94 (100.00%)

Unit: Million TOE.

5. CONCLUSIONS

The complete decomposition model provides a method for factor analysis of aggregate energy intensity and aggregate energy consumption. The present study has been conducted on the factor analysis for the change of energy intensity and energy consumption in Pakistan in 1960–1998. The results show that increase in aggregate energy intensity is mainly due to the structural effect while increase in aggregate energy consumption is due to both the activity effect and the structural effect. This may lead to the conclusion that there was inefficient use of energy in the country due to the change in economic structure and economic activities in the country. These results further indicate that improved efficiency of energy use could be due to the efficient use of energy by the relatively high energy-intensive group as compared to the inefficient use of energy by the low energy-intensive group in the country. However, we do not know the reasons for inefficiency of energy use; there may be system losses, lack of system reliability, inefficient management, poor institutional frameworks, and inefficient manpower. The main policy implication for the improvement of energy efficiency is the adoption of explicit conservation policies that go beyond the steps involved in rational energy pricing, public awareness efforts, audits of energy use, etc. Other methods to foster energy savings should also be promoted and supported.

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