WORKING PAPER 03/2011

Industrial energy efficiency in developing countries: A background note

UNITED NATIONS
INDUSTRIAL DEVELOPMENT ORGANIZATION

DEVELOPMENT POLICY, STATISTICS AND RESEARCH BRANCH
WORKING PAPER 03/2011

Industrial energy efficiency in developing countries: A background note

Mallory Compton
Overseas Development Institute

UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION
Vienna, 2011

Acknowledgements

This working paper was prepared by Mallory Compton, Overseas Development Institute, as background material for the UNIDO Industrial Development Report 2011, under the supervision of Ludovico Alcorta, Director, Development Policy, Statistics and Research Branch, UNIDO.

Table of contents

List of figures

List of boxes

List of tables

Executive summary

Improved industrial energy efficiency has many potential benefits, yet an optimal level of investment in efficient technologies is not achieved due to a variety of barriers. This report provides a literature review on this particular issue. We first provide an overview of various definitions, methods and current trends in industrial energy efficiency worldwide. We then discuss the benefits of energy efficiency through the various linkages between energy efficiency and productivity at the firm level, and between energy efficiency and growth at the macro level. We also summarize the literature on the barriers to investment in industrial energy efficiency. The appendix contains detailed findings and facts.

Though there are several definitions of energy efficiency measures, each with its respective strengths and weaknesses, most studies use a measure of energy intensity or the inverse, energy productivity.

Despite the clear benefits in theory, there is no clear consensus on the evidence linking energy efficiency and macroeconomic growth. There is evidence of a link between efficiency and firm-level productivity in the developed world, but little evidence exists from developing countries. Even in the developed world, where data are widely available, there is a lack of “both time series and plant level data on the appropriate mix of inputs by which we might more accurately assess the productivity impacts” (Worrell et al 2001:15). Many reports assert linkages between energy efficiency and benefits without clear evidence, thus clouding the discussion with uncertainty and ambiguity. There is also a lack of information on the cost effectiveness of industrial efficiency investments in developing countries.

Some of the most often cited barriers to investment in industrial energy efficiency, particularly in developing countries, include informational barriers on available benefits, for example, financial barriers such as an absence of credit, high risk of new technology, high transaction costs, shortage of sufficiently trained staff to implement new technologies and an absence of adequate policy and contracting institutions at the national level to encourage investment.

One constraining factor in this field of study is the lack of firm-level data from developing countries. The most relevant studies of developing countries on this subject use aggregated numbers; only a few scattered case-studies deal with micro-level data. There is a plethora of literature on potential benefits of improved productivity, but there seems to be no empirical or theoretical consensus on magnitude of benefit or mechanism for realizing them. The contradictions in empirical studies indicate the variation of conditions across countries that the relationship between productivity and economic growth is heterogeneous.

1 Introduction

Demand for energy is rising worldwide at an unsustainable rate. The IEA's 2008 *World Energy Outlook* reference scenario estimates that world primary energy demand will grow 1.6 percent per year on average between 2006 and 2030 to an overall increase of 45 percent. The majority of this growth will take place in developing countries, 87 percent of the projected increase in demand will come from non-OECD countries; 50 percent of total demand comes from China and India alone (IEA, 2008).

In terms of the global potential for increased energy productivity, the McKinsey Global Institute determines that 65 percent of all available positive return opportunities for investment are located in developing regions (Farrell and Remes, 2009:2). An estimated investment of US$ 90 billion in the next twelve years could save these developing countries US$600 billion by 2020 in energy savings per year (Farrell and Remes, 2009:2). This investment of US$ 90 billion is projected to be only half of the required investment to keep up with energy demand growth without improved efficiency measures (Farrell and Remes, 2009:2). Not only in these developing countries, but at the global level as well, industrial efficiency improvements to produce more economic output with less energy input is essential for reasons of energy supply security, economic competitiveness through improved industry profitability, improvement in livelihoods and environmental sustainability (Taylor et al, 2008:3).

Achieving greater economic output per unit of energy input can either be achieved from changes in economic structure or through technical energy efficiency gains. This report focuses on the benefits and barriers to technical energy efficiency gains, specifically in industry. Of the total global potential for efficiency gains in industrial sectors, 80 percent of the opportunities lie in developing countries (Farrell et al, 2008:13). This large potential is attributable to a number of factors, including "the larger scope to increase energy productivity in low-efficiency legacy assets in a number of regions […] and the fact that lower labor costs reduce capital requirements for many initiatives and make a broader set of actions on energy productivity economically viable" (Farrell et al 2008:13).

Improved industrial energy efficiency has many potential benefits, yet optimal investment in efficient technologies is not taking place due to a variety of obstacles. This report seeks to provide an overview and literature review to contribute to the discussion and research. The following section is an overview of various definitions, methods and current trends in industrial energy efficiency worldwide. Section three is a literature review of the suggested benefits through the various linkages between energy efficiency and productivity at the firm level and between energy efficiency and growth at the macro level. Section four summarizes cited barriers to industrial energy efficiency. The extended Appendix is a summation of various relevant findings and facts from literature which are too broadly defined for inclusion in the report. The sections of the appendix correspond to the topics covered in Sections 2 through 4 of this report.

2 Definitions, methods and trends

Though there are several definitions of energy efficiency measures, "energy intensity measures are often used to measure energy efficiency and its change over time […]. Energy-intensity measures are at best a rough surrogate for energy efficiency. This is because energy intensity may mask structural and behavioural changes that do not represent "true" efficiency improvements" (EIA, 2003). Energy intensity is simply a ratio of energy input to industrial output; an economic-thermodynamic type of efficiency measure. "In comparison to the application of thermal efficiency measurement, indices of energy consumption can be used to assess and compare energy performance for a broader set of objects: processes, factories, companies, and even countries" (Tanaka, 2008a:7). Most studies use a measure of energy intensity, or the inverse, energy productivity.

Industrial output can be measured using some sort of common physical unit at lower levels of aggregation, but will necessarily be measured in economic value taking account of purchasing power parity at economic or national levels of aggregation. It is well noted in the literature that even at the 2-digit SIC level of industrial classification, common physical output measures are not possible. There are a number of ways to measure output of industry but "it seems that value of production is the most desirable value-based output measure for use in an indicator of energy intensity" (Freeman, Niefer, & Roop, 1997:713). Differences between intensity measures using volume and those using value-based output may be attributable to measurement errors in price indexes, errors in industry specialization and coverage, or industry redefinitions (Freeman, Niefer, & Roop, 1997). Additional methodological issues (valuation & value judgements, energy quality problems, boundary problem, joint production problem, technical or gross energy efficiency) are summarized in Patterson (1993), and are not unique to energy intensity as a measure of efficiency.

Box 1 What is energy productivity?

Energy productivity is a useful tool with which to analyze the public-policy aims of demand abatement and energy efficiency because it encapsulates both. By looking merely in terms of shrinking demand, we are in danger of denying opportunity to consumers—particularly those in developing economies, an increasingly dominant force in global energy demand growth. Rather than seeking explicitly to reduce end-use demand, we should focus on using the benefits of energy in the most productive way.

Like labor or capital productivity, energy productivity measures the output and quality of goods and services generated with a given set of inputs. We measure energy productivity as the ratio of value added to energy inputs, which today is $79 billion of GDP per QBTU of energy inputs globally. This is the inverse of the energy intensity of GDP, measured as a ratio of energy inputs to GDP. This currently stands at 12,600 BTUs of energy consumed per dollar of output.

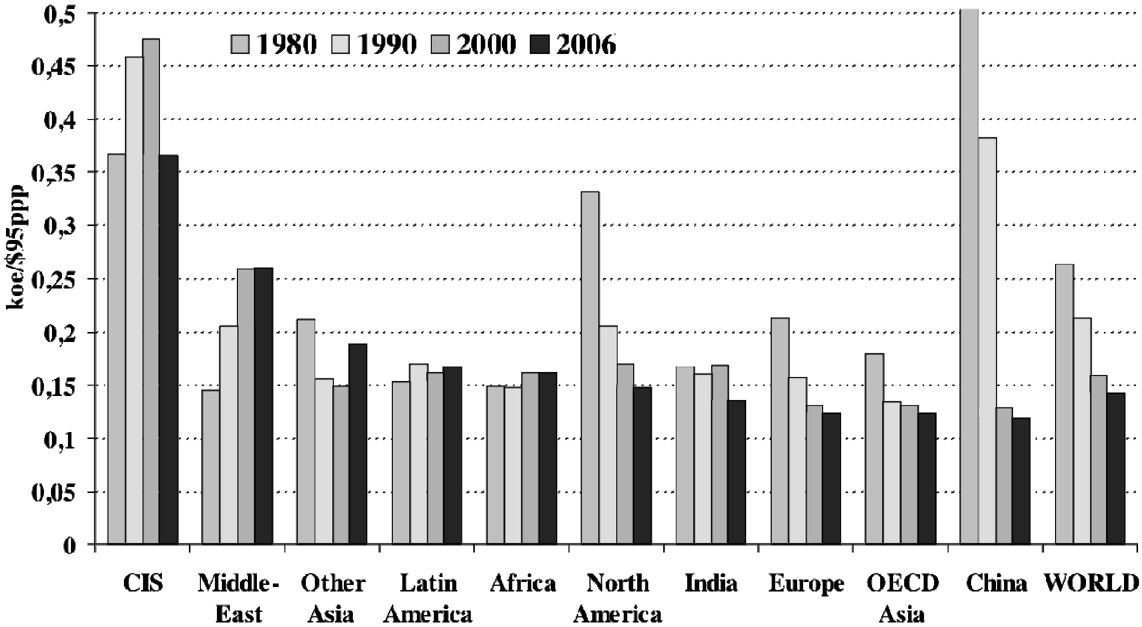
When identifying opportunities for energy productivity improvements, we focus on changes that rely on currently existing technologies, have an IRR of 10 percent or more, and avoid compromising the comfort or convenience valued by consumers. Our exclusive focus on economic opportunities means that making these investments would benefit the economy by freeing up resources to increase consumption or investment elsewhere.

Source: Farrell et al, 2008:12

If dealing with economic or industry-wide data, it is also possible to use a decomposition method. Applying the Laspeyres factorial decomposition method, energy use is decomposed into an activity effect, structural effect and an intensity effect; each is measured by keeping the other two constant (EIA, 2003). The commonly preferred index, however, is the Divisia index (Liu & Ang, 2007). This approach may be used to decompose time trends into different factors, such as structural factors and intensity, to measure energy savings over time, and uses time trend data (EIA, 2003). "Index decomposition analysis is the most rigorous technique currently available to address the issues of energy efficiency performance and to track its trend at the industry-wise or economy-wide level" (Liu & Ang, 2007:612). An improvement on the Divisia decomposition method is developed in Bor (2008).

Industrial Energy Efficiency Trends Over time

Figure 1 Energy intensity of industry

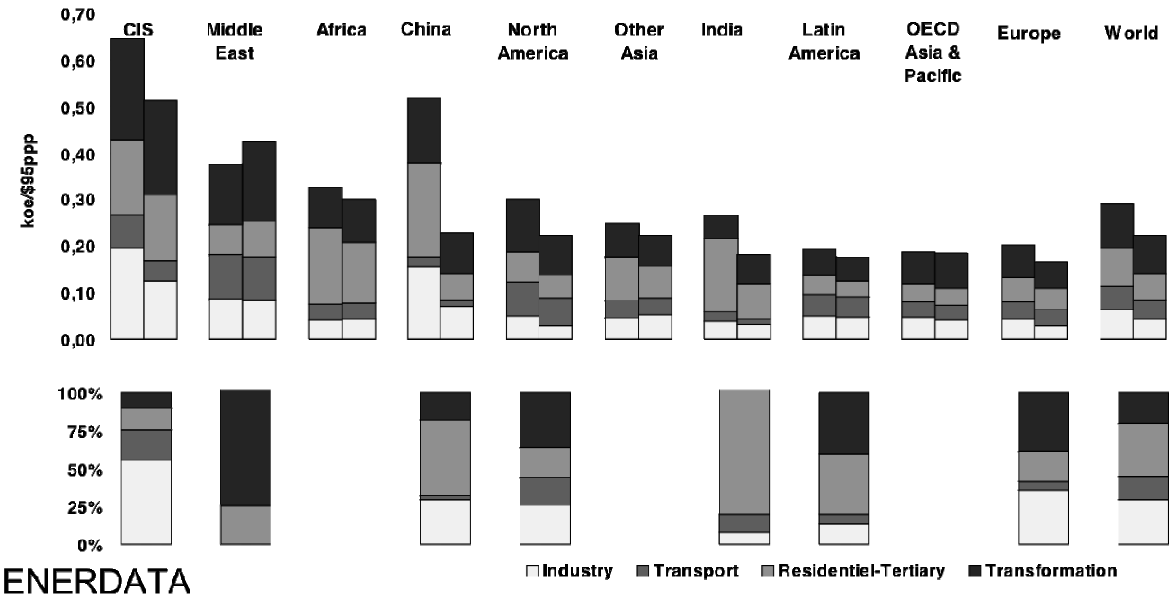


Source: WEC, 2008:26

The chart above demonstrates the trend in industrial energy intensity over the last two and a half decades (WEC, 2008). It is clear that the trends differ between the various regions. The global trend reveals decreasing energy intensity, which is to say an improvement in efficiency. Some regions, however, such as Latin America, Africa and the Middle East demonstrate a rise in intensity.

This second chart (below) shows that although total primary energy intensity is decreasing in almost all regions, energy intensity is static or increased between 1990 and 2006 in others. In developing countries, residential energy savings drive the reductions in aggregate energy intensity decline, largely by a substitution of modern fuel for traditional ones.

Figure 2 Primary energy intensity by sector (1990 and 2006)



Source: WEC, 2008:22

Figure 3 Energy Efficiency in Africa, as a region

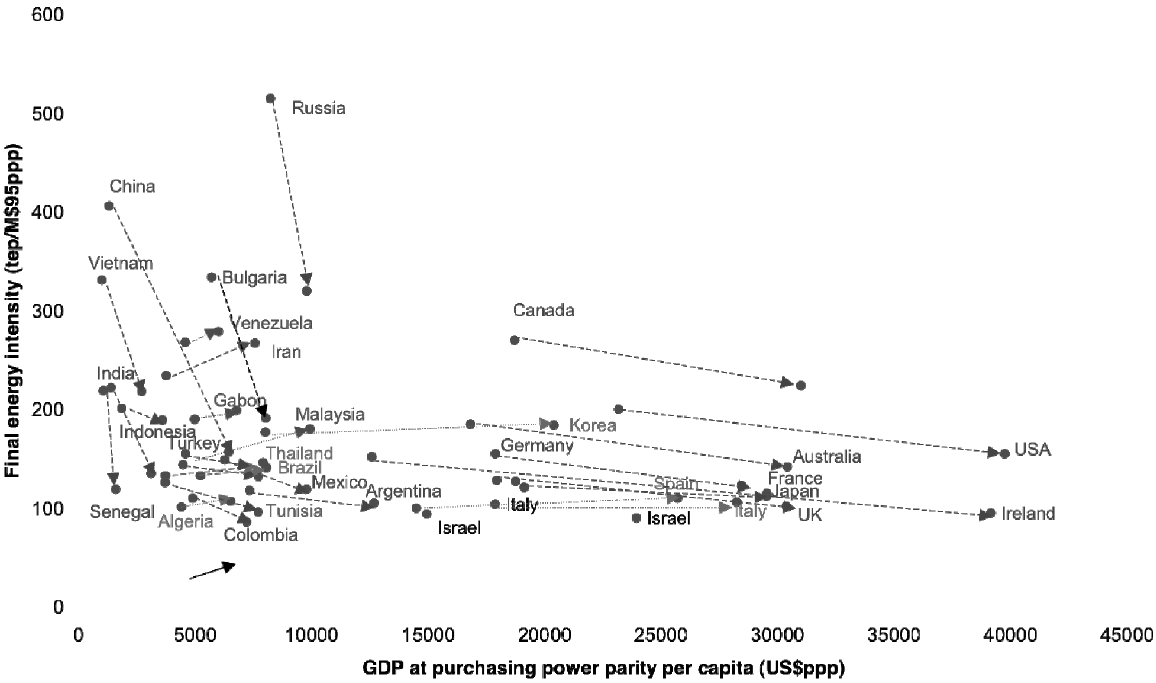
Energy Efficiency Indicators	Units	1980	1990	2000	2007
Key Indicators					
Primary energy intensity (at purchasing power parities (ppp))	koe/$05p	0.248	0.270	0.272	0.246
Primary energy intensity excluding traditional fuels (ppp)	koe/$05p	0.122	0.143	0.144	0.136
Primary energy intensity adjusted to EU structure (ppp)	koe/$05p	0.139	0.167	0.200	0.192
Final energy intesnity (at ppp)	koe/$05p	0.189	0.186	0.185	0.166
Final energy intensity at 2005 GDP structure (ppp)	koe/$05p	0.115	0.122	0.140	0.136
Final energy intensity adjusted to EU economic structure (ppp)	koe/$05p	0.104	0.119	0.143	0.137
CO2 intensity (at ppp)	kCO2/$05p	n.a.	0.433	0.425	n.a.
CO2 emissions per capita	tCO2/cap	n.a.	0.980	0.960	n.a.
Industry					
Energy intensity of industry (to value added) (at ppp)	koe/$05p	0.156	0.152	0.135	0.120
Energy intensity of manufacturing (at ppp)	koe/$05p	0.346	0.320	0.280	0.260
Unit consumption of steel	toe/t	11.160	0.800	0.590	0.400
CO2 intensity of industry (to value added) (at ppp)	kCO2/$05p	n.a.	0.320	0.275	n.a.
CO2 emissions of industry per capita	tCO2/cap	n.a.	0.200	0.170	n.a.

Source: http://www.worldenergy.org/documents/afriq_1.pdf

“Industry is the main sector driving energy intensity reduction in industrialized countries. In developing countries and regions, on the other hand, households are the main drivers. In China and the CIS, energy productivity improvements were almost equally driven by industry, energy conversion and households” (WEC, 2008:95). “If what has happened in industrial countries is indicative of future developments of the developing countries, in particular the high income ones, then it would be expected that the aggregate energy intensities of these countries will likely stabilize and/or decline as a result of the impacts from energy intensity change" (Liu & Ang, 2007:631). There is some evidence of convergence in energy productivity growth levels across developed and developing countries, which is conditional on country specific factors (Miketa & Mulder, 2005).

Though representing total economy energy intensity and limited in its representation of countries, the following chart is useful in identifying aggregate trends:

Figure 4 Trends in final energy intensity and GDP per capita (1990-2006)



Source: WEC, 2008:23

3 Causal effects of industrial energy efficiency on economic growth – benefits of industrial energy efficiency

The direction of causality in the relationship between economic growth and energy use is unclear. Theoretically, neo-classical and endogenous theories both suggest that energy use and efficiency are drivers of economic growth. Though there are many studies that find a direct relationship between productivity and energy efficiency in the industrialized world (see Worrell et al 2001), evidence from the developing world remains inconclusive. Few disaggregated studies have been conducted on this issue and the studies using data aggregated at the national or economic level indicate mixed findings. As quoted in Mishra et al (2009:212), Mehrara (2007:2940) states:

> [W]hen it comes to whether energy use is a result of, or a perquisite for, economic growth, there are no clear trends in the literature. Depending on the methodology, used, and country and time period studied, the direction of causality between energy consumption and economic variables has remained empirically elusive and controversial.

Further complicating the relationship is the extent to which economic growth and energy consumption can theoretically be decoupled, a question raised by ecological economists who argue thermodynamic laws limit such division. Below is a brief review of the various theories on the relationship between energy consumption, energy efficiency and economic growth, followed by a summary of a select list of empirical studies, and finally, a review of the main arguments and claims made by various institutions on the matter.

Theory

By incorporating energy end-use efficiency gains into a Cobb-Douglas production function, Wei (2007) theorizes about short-term and long-term effects of increased energy efficiency beginning with the production function specification:

$$X = aK_x^{\alpha} L_x^{\beta} (\tau E_x)^{1-\alpha-\beta}. \qquad \text{(eq. 1)}$$

Here, X is defined as gross output, K and L are specifications of capital stock and labour supply, respectively, and E is some measure of energy use, all of which are specified by input factor x. τ is a technological parameter, the increase of which indicates an improvement in energy efficiency. In the short term, energy use efficiency is found to lower the cost of non-energy and increase the output of non-energy goods. A 100 percent rebound effect is evident such that in the short term, energy efficiency gains have no effect on absolute energy use. In the long term, the impact on non-energy output of energy end use efficiency is positive. The long-term impact of energy use efficiency on total energy use is lower than the short-term impact. Wei also finds that energy use efficiency will increase real energy price in the long term.

Van Zon and Yetkiner modify the Romer model to include energy consumption of intermediates and to make them heterogeneous due to endogenous energy-saving technical change (2003). They find that economic growth rate positively depends on the rate of embodied energy-saving technical change, and that it also depends negatively on the rate of growth of real energy prices, implying that continuously rising real energy prices will tend to slow growth. Embodied technical change includes improvements in energy efficiency, thus positively linking improvements in energy efficiency to economic growth. They conclude that in an environment of rising energy prices, recycling energy tax proceeds in the form of R&D is necessary for both energy efficiency growth and output growth.

Sorrell (2009) highlights the conflict between those known as "conventional economists" and as "ecological economists" with regard to the effect of energy on growth. "The conventional wisdom (as represented by both neoclassical and 'endogenous' growth theory) is that increases in energy inputs play a relatively minor role in economic growth, largely because energy accounts for a relatively small share of total costs" (Sorrell 2009:1460). This view has been contested by ecological economists, who argue instead that the "increased availability of 'high quality' energy inputs has been the primary driver of economic growth over the last two centuries" (Sorrell 2009:1460). Ockwell further discusses this divide between conventional and ecological economics: "[…] for ecological economists, energy is a fundamental factor enabling economic production. Some commentators even argue that energy availability actually drives economic growth, as opposed to economic growth resulting in increased energy use (e.g. Cleveland et al., 1984). From this perspective, the possibility of decoupling energy use from economic growth seems more limited" (2008:4601). A challenge to the resolution of this debate is the absence of empirical consensus. "Sufficient empirical evidence does not yet exist to provide conclusive support for the claims of either the ecological or neo-classical schools of thought. Breaking down the evidence that does exist suggests that observed improvements in GDP/energy use ratios may be better explained by shifts towards higher quality fuels than by improvements in the energy efficiency of technologies" (Ockwell 2008:4604).

Empirical

Many studies on the link between aggregated energy efficiency/energy use and economic growth in the developing world have mixed results and unclear findings (Akinlo 2008; Mishra et al 2009; Lee and Chang 2008). While many studies from developed countries exist, only a handful of case studies in the developing world have attempted to identify the link between firm level energy use efficiency and productivity.

Table 1 below represents the direct firm-level benefits of greater energy use efficiency in industry. The list is based on a survey of 77 case studies of manufacturing firms from six OECD countries. When all of the savings (energy and productivity/non-energy) are incorporated, the average payback period for efficiency improvement projects is 1.9 years for this sample of case studies. When calculating energy savings only, the payback period is 4.2 years. Some benefits such as those involving valuation of emissions reductions and the work environment are subject to some measurement error. It must be noted that the results of these case studies are derived from developed economies' industrial sectors.

Table 1 Direct firm-level benefits of increased industrial energy use efficiency

Waste	Emissions	Operation and Maintenance
– Use of waste fuels, heat, gas – Reduced product waste – Reduced waste water – Reduced hazardous waste – Materials reduction	– Reduced dust emissions – Reduced CO, CO2, NOx, SOx emissions	– Reduced need for engineering controls – Lowered cooling requirements – Increased facility reliability – Reduced wear and tear on equipment/machinery – Reductions in labour requirements
Production	Working Environment	Other
– Increased product output/yields – Improved equipment performance – Shorter process cycle times – Improved product quality/parity – Increased reliability in production	– Reduced need for personal protective equipment – Improved lighting – Reduced noise levels – Improved temperature control – Improved air quality	– Decreased liability – Improved public image – Delayed or reducing capital expenditures – Additional space – Improve worker morale

Source: Worrell et al, 2001:2

A study of a US glass manufacturing subsector found support for a strong statistical link between energy intensity and productivity and of the resultant non-energy benefits (Boyd 2000). However, they find that the effects are industry specific. Whether or not the relationship is proportional depends on the industry subsector.

Adenikinju and Alaba (1999) sought to quantify the link between energy use and productivity performance in the Nigerian manufacturing sector. Their data covers 1970–1990 and was collected and provided by the Federal Office of Statistics; most variables are defined at the firm level with the exception of energy consumption which is defined at the industry level. They find a positive relationship between total factor productivity growth and energy consumption for most industries. Heavily subsidized energy prices encouraged industry over this period to depend on cheap energy for growth; industry therefore grew to be reliant on old and energy-inefficient technologies. Increasing energy prices would likely encourage energy efficiency investments, though a drastic increase in prices over a short period of time would risk mass firm shutdowns.

A survey of small-scale bricks and foundry clusters in India found a negative relationship between energy intensities and factor productivities. Using data created and collected for this study, Subrahmanya (2006) finds that those enterprises which utilize energy more productively are likely to use labour and capital more productively as well, although it may not lead to greater value addition in the process. The analysis reveals that for energy intensive clusters, greater energy use efficiency enables greater economization of production costs and the achievement of higher productivities and greater competitiveness. Basically, the competiveness of small enterprises in energy-intensive industries can be enhanced by improving their energy efficiency through reductions in energy intensity.

The following chart categorizes some of the most often cited benefits of improved energy efficiency. These are empirical claims published in a World Bank study, a McKinsey Global Institute report and other various research reports; these cited benefits are empirical, and are not solely based on theoretical grounds. Authors sometimes establish links between efficiency and benefit without describing the mechanism, leaving the connection less clear; these more ambiguous linkages are indicated by an asterisk in the table. A notable difference between Table 1 and 2 is the claim by Worrell et al. (2001) that greater energy efficiency will lead to reductions in labour requirements at the firm level, but some sources claim (as in Table 2) that overall employment would increase due to increased productivity and resulting growth.

Table 2 Indirect benefits of increased industrial energy use efficiency and increased productivity

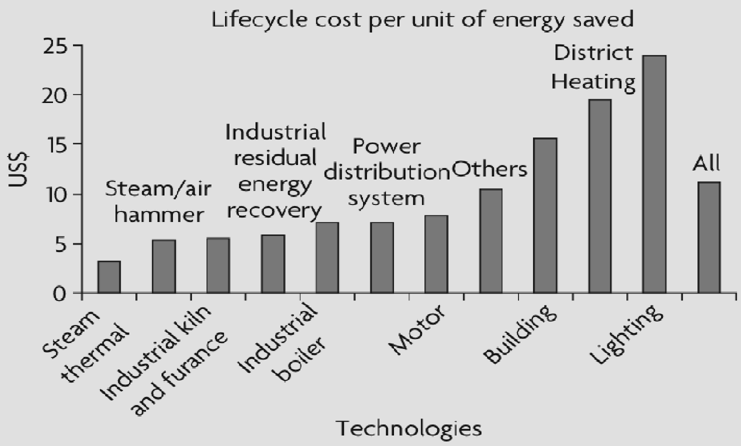
Benefit	Source	Justification
More economic output without requiring additional, possibly constrained, energy supply – firm and national level benefit	Taylor et al (2008), Semboya (1994), UNDP (2006), McKane et al (2007), Adenikinju & Alaba (1999); Boyd & Pang (2000)	This is particularly important in regions where electricity and energy supply are constrained, such as in many African and Asian countries. Not only will greater output be feasible without increasing energy demand, but less investment will be necessary in energy production capacity (WEC 2008:9).
Lower production/energy costs – at the firm level	UNDP-Kenya (2006), Farrell and Remes (2009), Semboya (1994), WEC (2008), McKane et al. (2007), Subrahmanya (2006)	"Costs vary among technologies and countries where energy efficiency measures are implemented, but often are only one-quarter to one-half the comparable costs of acquiring additional energy supply" (Taylor et al. 2008:27).
Economic competitiveness (through lower prices) – national and firm level benefit	Taylor et al. (2008), UNDP-Kenya (2006), Semboya (1994), WEC (2008), Surahmanya (2006)	At the firm level, higher efficiency will improve competitiveness via lower costs.
Creates jobs (indirectly) *	UNDP-Kenya (2006), IEA (2009),	By increasing use of high-tech efficient machinery, high-skill technicians will be in more demand. Also, by improving competitiveness, presumably the firm will grow and be able to employ more workers.
Improvement in livelihoods/ reduce poverty*	Taylor et al (2008), UNDP-Kenya (2006), WEC (2008)	Poverty is reduced by an increase in jobs.
Energy supply/price security and reduced uncertainty*	Taylor et al (2008), UNDP-Kenya (2006), World Bank (2006), IEA (2009), WEC (2008), McKane et al (2007), Farrell and Remes (2009)	Particularly for oil importing countries (WEC 2008:105).
Environmental sustainability	Taylor et al (2008), World Bank (2006), IEA (2009), UNDP (2006), WEC (2008) – extends availability of fossil resources	"Energy efficiency is favored in environmental improvement strategies because it reduces the need for energy development, transportation and distribution, onsite use, and all the associated environmental impacts" (Taylor et al. 2008:27)
Reduce import bill (nationally)	UNDP-Kenya (2006), Semboya (1994), UNDP (2000); Adenikinju & Alaba (1999); and improve balance of trade: UNDP-Kenya (2006), Semboya (1994), WEC (2008), Adenikinju & Alaba (1999)	"[E]nergy imports are replaced (in many countries) by domestically produced energy-efficient products and (energy) services" (UNDP 2000:185). Greater industrial outputs can increase exports.

Much effort has been devoted to understanding the existence and scope of potential “rebound” effects of the Jevon’s/Khazzom-Brooks variety, which asserts that efficiency improvements may not necessarily result in proportional decreases in total energy use. Sorrell and Dimitropoulos (2008) find that direct rebound effects may be larger for producers (industry) than for households. They also find that the effects may be larger in developing countries. Ockwell (2008) also asserts that rebound effects (generally not specific to industry) will be greater in developing countries. Direct rebound effects are defined as an increase in consumption of an energy input as the price of that input decreases with increased efficiency. Madlener et al. conclude their summary of debates on the rebound effect by determining that “increases in energy efficiency are no panacea for either energy conservation or economic growth and welfare” (2009:9).

Overall, there is no clear consensus on the evidence and theory linking aggregated growth and energy efficiency. There is evidence of a link between efficiency and firm-level productivity in the developed world, but little evidence from developing countries exists. Even in the developed world, where data is much more available, there is a lack of “both time series and plant level data on the appropriate mix of inputs by which we might more accurately assess the productivity impacts” (Worrell et al 2001:15). Many reports assert linkages between energy efficiency and benefits without clear evidence, thus clouding the discussion with uncertainty and ambiguity. A clear idea of the cost effectiveness of industrial efficiency investments for the developing world are lacking. The box below comes from a World Bank report and provides helpful insights on the topic, though not specific to developing countries or industrial investments.

Box 2 Cost effectiveness of general energy efficiency measures

A survey of 455 energy efficiency investments implemented in 11 industrialized and developing countries shows that the cost per unit of energy saved (present value over lifetime of the investment of 10 years) is on average US$76 per toe or US$11 per barrel of oil (in year 2006 U.S. dollars). This compares very favorably with the prevailing market price of energy, for example, more than US$60 per barrel of oil (in 2006 U.S. dollars). The figure below shows the wide range of cost effectiveness of various technologies. Still, more than 80 percent of the projects surveyed recovered their investment costs through energy cost savings within 30 months. Even one of the least cost-effective types of energy efficiency investments from the sample, in buildings, has life-cycle costs (8.6 U.S. cents per kWh over a 10-year lifetime) that are substantially below the costs that most final consumers have to pay for electricity. Not surprisingly, investments in countries such as India or China tend to be far more cost-effective than in industrialized countries.



Source: Shi 2007 in Taylor et al 2008:29

4 Barriers to entry of energy efficient technologies in industry

After reviewing the expected benefits of improved energy efficiency within industry, the problem is now to overcome the many barriers preventing optimal investment. The chart below documents some commonly cited barriers to entry of energy efficient technologies in industry, particularly in developing countries. Some of the most often cited barriers include informational barriers such as lack of knowledge of available benefits, financial barriers in the way of an absence of credit, shortage of sufficiently trained staff to implement new technologies, and a lack of adequate policy at the national level to encourage investments. This list may not be comprehensive of all the literature, it is simply a starting point to understand the most commonly identified barriers; the broader classifications in the left column are those suggested by Praetorius & Bleyl (2006).

Table 3 Barriers to investment in efficient technologies in relevant to industries in developing countries

Informational Barriers	Ignorance of technology availability & benefits	Reddy 1991; UNDP 2000; McKane 2007; Farrell 2009; Taylor et al 2008; Preaetorius & Bleyl 2006; WEC 2008;
	Institutional barriers to knowledge, communication and technology flows	Meyers 1998;
Financial Barriers	Lack of available funds/ absence of credit	Reddy 1991; UNDP 2000; Farrell 2009; Taylor et al 2008; Meyers 1998; WEC 2008;
	First-price sensitivity/high capital costs (magnified by the lack of credit markets)	UNDP 2000; Reddy 1991; Behrens et al 2009; Meyers 1998; WEC 2008;
Technological barriers	Unavailability of efficient equipment (technology available but not produced)	Reddy 1991; Meyers 1998;
	Focus on individual component efficiency, not whole system efficiency	McKane et al 2007;
	Misapplication of efficient technologies	McKane et al 2007;
	Shortage of trained technical personnel to maintain/install new equipment	Reddy 1991; McKane et al 2007; Taylor et al 2008; UNDP 2000;
Discrepancies in discount rate	Uncertainty about future energy prices/economic uncertainty	Reddy 1991; McKane et al 2007; Taylor et al 2008;
	High user discount rates	Taylor et al 2008; Behrens et al 2009; Meyers 1998;
	Slow rate of capital turnover/ infrequency of capital investments	McKane et al 2007;
	Perceived risk of implementing the new/unfamiliar technology	McKane et al 2007; Taylor et al 2008; Meyers 1998; IEA 2009;
	Indifference to energy costs/relative insignificance of energy costs to total costs	Reddy 1991; Meyers 1998;
	Below long-run marginal cost pricing and other price distortions	Taylor et al 2008; Meyers 1998; IEA 2009;
	High transaction costs	Behrens et al 2009; Taylor et al 2008; Meyers 1998;
Diversity of investment criteria and limited resources	Inherited inefficient equipment/indirect purchase decisions	Reddy 1991; UNDP 2000; Meyers 1998; WEC 2008;
	Limited fuel options/supply	UNDP 2000;
	Historically or socially formed investment patterns	UNDP 2000; McKane 2007;
	Mismatch of the incidence of investment costs and energy savings	Taylor et al 2008;
	Import of inefficiently used plants and vehicles	UNDP 2000; Meyers 1998;
Policy/political barriers	Political uncertainty/ policy instability	Taylor et al 2008;
	Weak contracting institutions	Taylor et al 2008; Meyers 1998;
	Absence of effective energy efficiency policy at national level	Reddy 1991; UNDP 2000; Behrens et al 2009; Taylor et al 2008;
	Inappropriate energy pricing and cross-subsidising	UNDP 2000; Farrell 2009; Meyers 1998;
	Skills-short government	Reddy 1991; Meyers 1998;
	Government without adequate training facilities	Reddy 1991;
	Government without access to necessary hardware and software	Reddy 1991;

Meyers (1998) suggests that the barriers related to macroeconomic conditions, energy pricing, international flows of technology, capital and knowledge, and institutional weaknesses are most relevant to developing countries.

The World Bank sponsored the Three Country Energy Efficiency Programme, which sought to finance energy efficiency in Brazil, China and India, and has considerably contributed to understanding the factors that best foster investment in energy efficiency. In these countries, the World Bank finds that "the core of the problem […] lies in the intertwined problems of perceived high risk driving up implicit discount rates associated with projects, currently high transaction costs, and difficulties in structuring workable contracts for preparing, financing, and implementing energy efficiency investments" (Taylor, et al 2008:6). The report stresses that barriers are related to institutional issues: "[…] two core economic functions that are dependent upon the strength of prevailing market institutions are usually critical for efficient energy efficiency investment: (i) outsourcing governed by contracts to allow sufficient specialization, and (ii) deep and efficient financial markets for financing energy-efficient investments (including both initial and retrofit investments)" (Taylor et al 2008:51-52). The policy solutions to these barriers should be specific and tailored to local environments. The box below offers a generalized guide to policymaking in the face of barriers to investments in energy efficiency.

Box 3 Generalized model for developing new energy efficiency investment delivery mechanisms in developing countries

Part I: Understand the **institutional environment** within which energy efficiency service transactions take place.

Part II: Pay careful attention to the **three requisites** that must be fulfilled within the respective institutional environment.

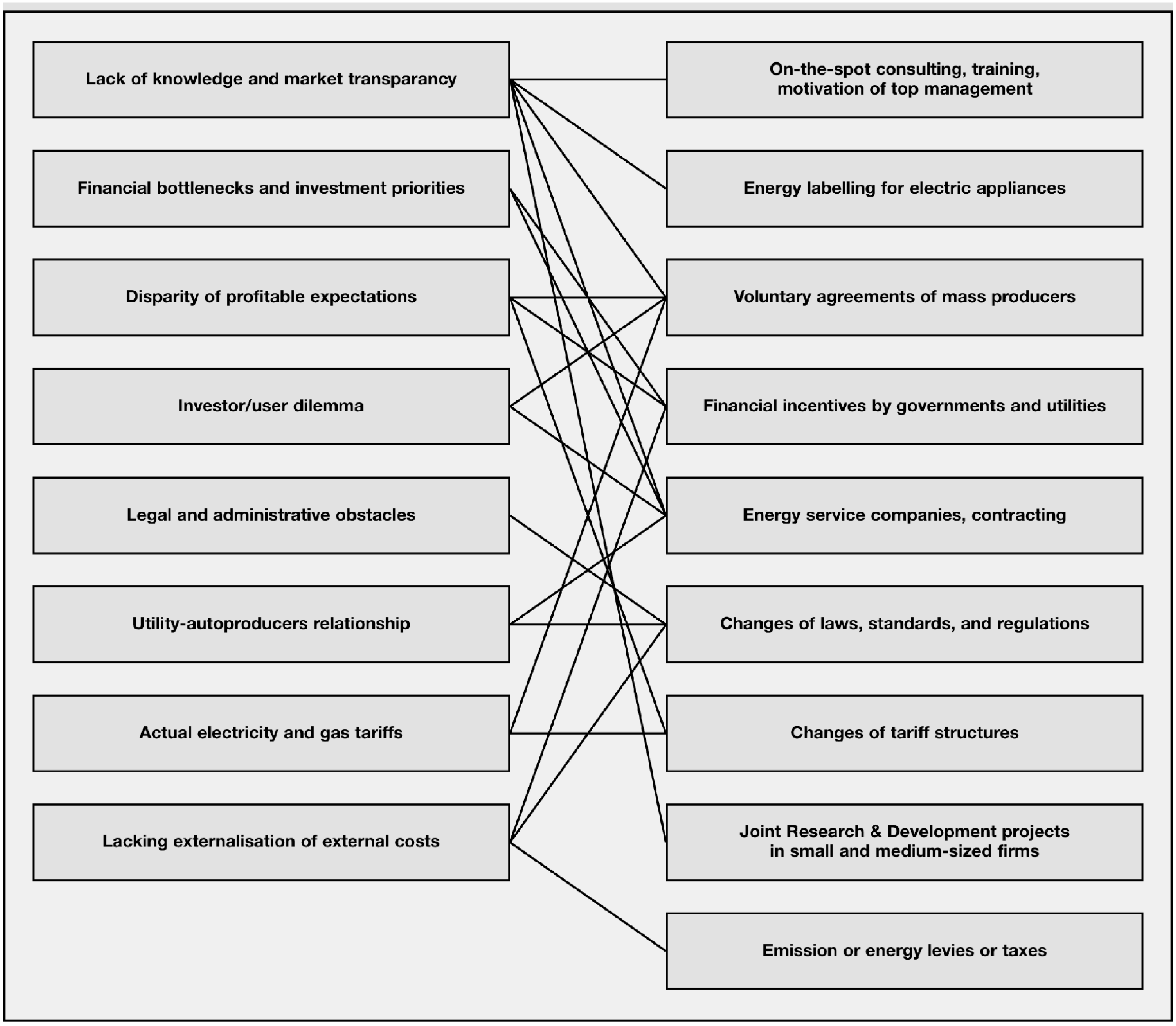
- Marketing/technical assessment
- Financing
- Incentives

Part III: Tailor the **institutional arrangements** for delivering the three requisites to the institutional environment within which the transaction is to take place.

Source: Taylor et al 2008:68.

The chart below pairs general types of investment barriers to energy efficiency by industry, including a policy solution. Though not detailed, this chart from UNDP (2000) provides an idea of the kind of policies required to overcome the above barriers. Many of the policy solutions have multiple purposes. Voluntary agreements of mass producers, for example, are suggested to resolve information/market transparency problems, disparity of profitable expectations, investor/user dilemmas as well as incorporating externalities into costs. For more information on voluntary agreements to spur investment in energy efficient technologies, see Oikonomou, et al. 2009 and Price &Worrell 2002. It is important to note that some of the policy recommendations in the table may be taken from successful experiences in the developed world and may not be directly transferable to the developing world. A more detailed discussion of barriers and their policy solutions with specific attention to developing countries can be found in Reddy (1991).

Figure 5 **Barriers to investment and policy solutions**



Source: World Energy Assessment, UNDP 2000:206.

A further list of policies or steps to spur investment in efficiency measures for industry is found in ESMAP (2006), however, this list is not specific to developing countries:

- Regulation measures
- Tax incentives
- Energy efficiency funds and low interest loans
- Performance codes, standards, incentives and regulations
- Mandatory/compulsory energy efficiency targets
- Technical assistance and small business programmes
- Energy audits for factories
- Product labelling, rating, certification and retro-commissioning
- Energy conservation management
- Recognition programmes, technology adaptation and upgrades; and bulk procurements

5 Conclusions

A constraining factor in this field of study is the lack of firm-level data. The most relevant studies of developing countries use aggregated numbers; only a few scattered case studies deal with micro-level data. There is a plethora of literature on *potential* benefits of improved productivity, but there seems to be little empirical or theoretical consensus on the scope of the benefits or the mechanism for realizing these. The contradictions in empirical studies indicate the variation of conditions across countries, making the relationship between productivity and economic growth heterogeneous.

Despite this ambiguity, there is some consensus on the barriers to optimal investment in efficiency measures. Lack of available credit, high risk, high transaction costs, insecure contracting institutions, and lack of sufficient technical skills are the most frequently cited hurdles to productivity investments. There is also consensus that policies should be tailored to individual specificities to ensure that the impact of these five factors is reduced.

References

Adenikinju, A., & Alaba, O. (1999). Energy use and productivity performance in the Nigerian manufacturing sector (1970-1990). *OPEC Review* (September), 251-264.

Akinlo, A. E. (2008). Energy consumption and economic growth: Evidence from 11 Sub-Saharan African countries. *Energy Economics , 30*, 2391-2400.

Andrews-Speed, P. (2009). China's ongoing energy efficiency drive: Origins, progress and prospects. *Energy Policy , 37*, 1331-1344.

Ang, B. (2006). Monitoring changes in economy-wide energy efficiency: From energy–GDP ratio to composite efficiency index. *Energy Policy , 34*, 574–582.

Ayers, R. U., Turton, H., & Casten, T. (2007). Energy Efficiency, sustainability and economic growth. *Energy , 32* (5), 634-648.

Behrens, A., Bird, N., & Fischer, G. (2009). *The financing of the Global Energy Efficiency and Renewable Energies Fund (GEEREF).* Brussels: European Parliament.

Bernard, J.-T., & Cote, B. (2005). The measurement of the energy intensity of manufacturing industries: a principal components analysis. *Energy Policy , 33*, 221-233.

Boyd, G. A. (2000). Estimating the linkage between energy efficiency and productivity. *Energy policy), 28* (5), 289-296.

Bor, Y. J. (2008). Consistent multi-level energy efficiency indicators and their policy implications. *Energy Economics , 30*, 2401-2419.

Brookes, L. (2000). Energy efficiency fallacies revisited. *Energy Policy , 28*, 355-366.

Cornillie, J., & Fankhauser, S. (2004). The energy intensity of transition countries. *Energy Economics , 26*, 283-295.

Department of Energy & Climate Change. (2009). *The Road to Copenhage: The UK Government's case for an ambitous international agreement on climate change.* Norwich: The Stationery Office.

Dimitropoulos, J. (2007). Energy productivity improvements and the rebound effect: An overview of the state of knowledge. *Energy Policy , 35*, 6354-6363.

EIA. (2003, June 02). *Energy Efficiency Measurement Discussion*. Retrieved July 9, 2009 from EIA: http://www.ei.doe.gov/emeu/efficiency/measure_discussion.htm

Energy Sector Management Assistance Program (ESMAP). (2006). *Energy Efficiency Investment Forum: Scaling up Financing in the Developing World.* Washington DC: The World Bank Group.

Fan, Y., Liao, H., & Wei, Y.-M. (2007). Can market oriented economic reforms contribute to energy efficiency improvement? Evidence from China. *Energy Policy , 35*, 2287-2295.

Farell, D., & Remes, J. (2009). *Promoting energy efficiency in the developing world.* McKinsey & Company.

Farrell, D., & Remes, J. (2008). *How the World should invest in energy efficiency*. McKinsey & Company.

Farrell, D., Remes, J., Bressand, F., Laabs, M., & Sundaram, A. (2008). *The case for investing in energy productivity.* McKinsey Global Institute.

Freeman, S. L., Niefer, M. J., & Roop, J. M. (1997). Measuring industrial energy intensity: practical issues and problems. *Energy Policy , 25* (7-9), 703-714.

Gale, B., & Pang, J. (2000). Estimating the linkage between energy efficiency and productivity. *Energy Policy , 28*, 289-296.

Gardner, T. A., & Joutz, F. L. (1996). Economic Growth, Energy Prices and Technological Innovation. *Souther Economic Journal , 62* (3), 653-666.

Geller, H., & Attali, S. (2005). *The Experience with Energy Efficiency Policies and Programmes in IEA Countries: Learning from the Critics.* Paris: IEA.

Geller, H., Harrington, P., Rosenfeld, A. H., Tanishima, S., & Unander, F. (2006). Policies for increasing energy efficiency: Thirty years of experience in OECD countries. *Energy Policy , 34*, 556-573.

Gillingham, K., Newell, R., & Palmer, K. (2006). Energy Efficiency Policies: a retrospective examination. *Annual Review of Environmental Resources , 31*, 161-192.

Howarth, R. B., Schipper, L., & Andersson, B. (1993). The Structure and Intensity of Energy Use: Trends in Five OECD Nations. *The Energy Journal , 14* (2), 27-46.

Howarth, R., Haddad, B., & Paton, B. (1997). Energy Efficiency and Economic Growth. *Contemporary Economic Policy , 15*, 1-9.

Howarth, R., Haddad, B., & Paton, B. (2000). The economics of energy efficiency: insights from voluntary participation programs. *Energy Policy , 28*, 477-486.

Hu, J.-L., & Wang, S.-C. (2006). Total-factor energy efficiency of regions in China. *Energy Policy , 34,* 3206-3217.

IEA. (2009). *Boosting the economy with energy efficiency financing.* Paris: International Energy Agency.

IEA. (2007). *Tracking Industrial Energy Efficiency and CO2 Emissions.* Paris, France: IEA.

IEA. (2008). *World Energy Outlook 2008: Executive Summary.* Paris: International Energy Agency.

IEA. (2008). *Worldwide Trends in Energy Use and Efficiency.* Paris, France: IEA/OECD.

Jenne, C. A., & Cattell, R. K. (1983, April). Structural change and energy efficiency in industry. *Energy Econonomics* , 114-123.

Lee, C.-C., & Chang, C.-P. (2008). Energy consuption and economic growth in Asian economies: A more comprehensive analysis using panel data. *Resource and Energy Economics , 30*, 50-65.

Liu, N., & Ang, B. (2007). Factors shaping aggregate energy intensity trend for industry: Energy intensity versus product mix. *Energy Economics , 29*, 609-635.

Lovins, A. (2005, September). More profit with less carbon. *Scientific American* , 74-82.

Madlener, R., & Alcott, B. (2009). Energy Rebound and Economic Growth: A review of the main issues and research needs. *Energy , 34* (4), 370-76.

McKane, A., Price, L., & de la Rue du Can, S. (2007). Policies for Promoting Industrial Energy Efficiency in Developing Countries and Transition Economies. *Background Paper for the UNIDO Side Event on Sustainable Industrial Development* (pp. 1-87). Vienna: UNIDO.

McKinsey & Company. (2009). *Pathways to a Low-Carbon Economy: Version 2 of the Global Greenhouse Gas Abatement Cost Curve.* McKinsey & Company.

Meyers, S. (1998). *Improving energy efficiency: strategies for supporting sustained market evolution in developing and transitioning countries.* Berkely: Lawurence Berkely Laboratory.

Miketa, A., & Mulder, P. (2005). Energy productivity across developed and developing countries in 10 manufacturing secors: Patterns of growth and convergence. *Energy Economics , 27*, 429-453.

Mills, E. (2003). Risk transfer via energy savings insurance. *Energy Policy , 31*, 273-281.

Mishra, V., Smyth, R., & Sharma, S. (2009). The energy-GDP nexus: Evidence from a panel of Pacific Island countries. *Resource and Energy Economics , 31*, 210-220.

Ockwell, D. (2008). Energy and economic growth: Grounding our understanding in physical reality. *Energy Policy , 36*, 4600-4604.

Oikonomou, V., Patel, M., van der Gaast, W., & Rietbergen, M. (2009). Voluntary agreements with white certificates for energy efficiency improvement as a hybrid policy instrument. *Energy Policy , 37*, 1970-1982.

Pandey, R. (2002). Energy policy modeling: agenda for developing countries. *Energy Policy , 30*, 97-106.

Patterson, M. G. (1996). What is energy efficiency?: Concepts, indicators and methodological issues. *Energy Policy , 24* (5), 377-390.

Praetorius, B., & Bleyl, J. W. (2006). Improving the institutional structures for disseminating efficiency in emerging nations: a case study for energy agencies in South Africa. *Energy Policy , 34*, 1420-1531.

Price, L., & Worrell, E. (2002). *Overview of Voluntary Agreements in the Industrial Sector,.* Energy Analysis Department, Environmental Energy Technologies Division. Berkeley: Lawrence Berekely National Laboratory.

Reddy, A. K. (1991). Barriers to imporovements in energy efficiency. *Energy Policy , 19* (10), 953-961.

Semboja, H. (1994). The effects of an increase in energy efficiency on the Kenya economy. *Energy Policy , 22* (3), 217-225.

Smulders, J., & de Nooij, M. (2003). The impact of energy conservation on technology and economic growth . *Resource and Energy Economics , 25* (1), 59-79.

Sorrell, S. (2009). Jevons' Paradox revisited: The evidence for backfire from improved energy efficiency. *Energy Policy , 37*, 2310-2317.

Sorrell, S., & Dimitropoulos, J. (2008). The rebound effect: Microeconomic definitions, limitations and extensions. *Ecological Economics , 65*, 636-649.

Stern, D. I., & Cleveland, C. J. (2004). *Energy and Economic Growth.* Rensselaer Polytechnic Institute. Troy: Rensselaer Working Papers in Economics.

Stern, N. (2007). *The Economics of Climate Chnage: The Stern Review.* Cambridge: Cambridge University Press.

Subrahmanya, B. (2006). Energy intensity and economic performance in small scale bricks and foundry clusters in India: does energy intensity matter? *Energy Policy , 34*, 489-497.

Taichen, C., & Jin-Li, H. (2007). Renewable energy and macroeconomic efficiency of OECD and non-OECD economeis. *Energy Policy , 35*, 3606-3615.

Tanaka, K. (2008). *Assessing Measures of Energy Efficiency Performance and their Application in Industry.* Paris, France: IEA.

Tanaka, K. (2008). Assessment of energy efficiency performance measures in industry and their application to policy. *Energy Policy , 36*, 2887-2902.

Taylor, R., Govindarajalu, C., Levin, J., Meyer, A. S., & Ward, W. A. (2008). *Financing Energy Efficiency: Lessons from Brazil, China, India and Beyond.* Washington DC: The World Bank Group.

Thompson, P. (1997). Evaluating energy efficiency investments: accounting for risk in the discounting process. *Energy Policy , 25* (12), 989-986.

Tonn, B., & Peretz, J. (2007). State-Level benefits of energy efficiency. *Energy Policy , 35*, 3665-3674.

UNDP. (2006). *Achieving Energy Efficiency in Malaysia.* Kuala Lumpur: United Nations Development Programme, Malaysia.

UNDP. (2000). *World Energy Assessment: Energy and the challenge of sustainability.* New York, New York: United Nations Development Program.

UNDP-Kenya. (2006). *Investors guide to energy efficiency.* Nairobi: United Nations Development Programme.

UNESCAP. (2008). *Statistical yearbook for Asia and the Pacific*. Retrieved June 29, 2009 from http://www.unescap.org/stat/data/syb2008/28-Energy-supply-and-use.asp

van Zon, A., & Yetkiner, I. H. (2003). An endogenous growth model with embodied energy-saving technical change. *Resource and Energy Economics , 25*, 81-103.

Wei, T. (2007). Impact of energy efficiency gains on output and energy use with Cobb-Douglas production function. *Enery Policy , 35*, 2023-2030.

Wiel, S., & Ega, C. (2006). Energy efficiency standards and labels provide a solid foundation for economic growth, climate change mitigation, and regional change. *Energy for Sustainable Development , 10* (3), 54-64.

Wiel, S., & McMahon, J. (2003). Governments should implement energy-efficiency standards and lables -- cautiously. *Energy Policy , 31*, 1403-1415.

World Bank. (2006). *Improving Lives: World Bank Group Progress on Renewable Energy and Energy Efficiency Fiscal Year 2006.* Washington DC: The World Bank Group.

World Bank. (2005). *World Bank Group Progress on Renewable Energy and Energy Efficiency: 1990-2004.* Washington DC: The World Bank Group.

World Energy Council. (2008). *Energy Efficiency Policies around the World: Review and Evlauation.* London: World Energy Council.

Worrell, E., Ruth, M., Laitner, J., & Finman, H. (2001). *Productivity benefits of industrial energy efficiency measures.* Ernest Orlando Lawrence Berkeley National Laboratory. Berkeley: Lawrence Berkeley National Laboratory.

Worrell, E., van Berkel, R., Fengqui, Z., Menke, C., Schaeffer, R., & Williams, R. O. (2001). Technology transfer of energy efficient technologies in industry: a review of trends and policy issues. *Energy Policy , 29*, 29-43.

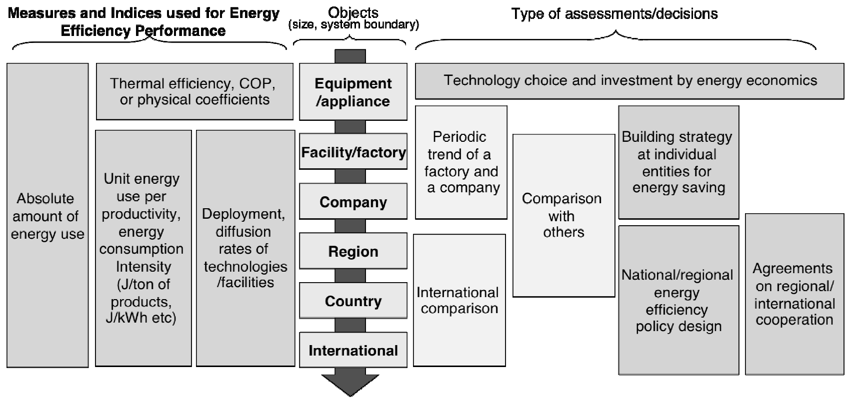
Zhou, P., & Ang, B. W. (2008). Linear programming models for measuring economy-wide energy efficiency performance. *Energy Policy , 36*, 2911– 29

Appendix

Table 1 Indicators and measurement of industrial energy efficiency

Source	Purpose	Methodology	Indicator definitions/types & Issues
Patterson, Murray G. "What is energy efficiency?: Concepts, indicators and methodological issues." Energy Policy 24, no. 5 (1996): 377-390.	Critical review of energy efficiency definitions and how they are operationalized; and methodological issues with each	Literature review	1. Thermodynamic definitions: Useful energy output/sum of all energy inputs - for a particular system, process or sector. Only "useful" inputs and outputs are captured. Limited comparability without adjusting for energy quality. Actual efficiency/ideal efficiency will measure how close a real system comes to an ideal system, but is limited in applicability to real world systems.
			2. Physical-thermodynamic definitions: Output/Energy input. Advantages of this kind of measure: can be objectively measured; can reflect what consumers are actually requiring in terms of end use service; can be compared in longitudinal/time series analyses. Must be defined on a sectoral basis in that the "output" measure will vary across industries (i.e., tonnes of bricks, litres of milk, cubic metres of wood, etc.). Therefore, economy-wide aggregates are not feasible.
			3. Economic-thermodynamic: Energy: GDP ratio - Can be applied to various levels of aggregation but cannot differentiate between changes in technical energy efficiency and changes such as sectoral mix, energy-labour substitution, and changes in energy input mix. GDP should account for purchasing parity for comparisons. Energy input: output ($) can be used at sectoral level but cannot always account for indirect energy use (i.e., sunlight in farming). Energy productivity ratio - GDP/Energy: focuses attention on the productive use of energy, and complimentary measure to capital & labour productivity analyses. In conjunction with K&L productivity measures, it can provide insight into whether energy inputs act as complements or substitutes. GDP/Energy may change by substitution, not by changes in technical efficiency (see technical or gross energy efficiency below)
			4. Economic: Energy input (in $ value): Output $ - accounts for variations in energy quality: requires careful calculation of 'ideal prices' to reflect marg. rate of transformation in prod. or MRS in consumption of inputs. Most common pure econ. indicator: national energy input ($)/national output ($GDP) - requires value judgments (see below).
			Methodological issues: 1) Valuation & value judgments - to define energy output requires defining "useful energy" which may fail to capture use of "waste heat," for example. Not all end uses are adequately included in measurement. 2) Energy quality problem - affects all indicators, occurs when different sources/end uses of energy are

			compared. Enthalpic measurements only measure heat content and do not distinguish between high-low quality of energy source (i.e. electricity-coal). Causes difficulty in aggregating, but is equally problematic at the micro-level. OECD thermal equivalents or fossil fuel equivalents can be used to account for these differences. 3) Boundary problem - only certain inputs are considered, non-commercial inputs are often excluded from efficiency indicators (gathered wood, sunlight, etc are not measured). Also, how far back to trace primary energy inputs? Do you account for energy losses in capturing & refining oil when using refined oil as an input? This latter issue can be accounted for by using the *quality equivalent methodology* (see Patterson 1993). 4) Joint production problem - arises when two different goods are produced using the same energy input, (raising a sheep produces both wool and meat), the problem is in differentiating input energy: output. Solving the problem requires arbitrary decisions about allocation. Regression analysis is useful when inputs or outputs are produced in quantities not proportional to each other. 5) Technical or gross energy efficiency - most indicators (particularly economic-thermodynamic) measure gross energy efficiency in a system/process/sector, which can be affected by structural factors (sectoral mix, energy input mix, increased mechanisation, and energy-for-labor substitution changes); meaning that the indicator does not capture exclusively technical efficiency changes. Technical and gross energy efficiency indicators are meant to measure different things.
Tanaka, Kanako. "Assessment of energy efficiency performance measures in industry and their application to policy." Energy Policy 36 (2008): 2887-2902.	Describe indices of energy efficiency performance in industry, which will be used in policymaking/ implementation processes, and to clarify the characteristics of each index, noting advantages and disadvantages, political implications, and links to policy framework.	Literature review and case study of Japan's iron and steel industry	"*Thermal energy efficiency of equipment* – This is expressed by: *energy output/energy input*, for end-use technology and energy conversion technology. For example, the energy efficiency of a steam boiler is energy amount as steam output divided by input heat to boil the water inside. In the case of motors, it should be power output divided by input electricity" (2888).
			(1) "*Energy consumption intensity (unit energy consumption, specific energy consumption)* – For this index, the *energy consumption* is divided by *the physical output value* (or some economic value) thereof. In a similar way to point (1), it can be expressed as energy input/output. In comparison to the application of thermal efficiency measurement, indices of energy consumption can be used to assess and compare energy performance for a broader set of objects: processes, factories, companies, and even countries. A recent IEA publication (IEA, 2007b) called a statistical tool, as one of MEEPs, "indicator", which measures energy use based on physical production of industrial products. This indicator is not influenced by price fluctuations (IEA, 2007a, b) and can be directly related to process operations and technology choice. The denominator of energy intensity is a physical value, so comparison of energy use in different units and aggregate efficiency for the whole of manufacturing is effectively impossible without the conversion of the physical units into a common value. Even at disaggregated levels like a single industry, the energy data corresponding to products and processes are not always forthcoming. Another problem related to the energy consumption intensity index is the definition of proper and comparable boundaries (boundary definition) (see Appendix A)" (2888).

			(2) "*Absolute amount of energy consumption – heat value* – This measure is sometimes used as MEEP. It loses its relevance from an energy efficiency perspective if it is not accompanied by an indication of production volumes. A problem similar to *energy consumption intensity* arises when we compare various boundary definitions" (2888).
			(3) "*Diffusion rates of energy-efficient facilities/types of equipment* – This measure indicates the rate of deployment of a specific technology, which has been identified as being energy efficient. Individual technologies share some common features including energy performance, with slight variations from one location of use to the other. The rate of diffusion of well-identified energy efficient technologies can therefore indicate progress towards enhanced energy efficiency – assuming that installation implies actual use of the equipment. (The application of, and issues related to the measures are discussed in Section 5.2)." (2888).
			Page2889: 
EIA. (2003, June 02). *Energy Efficiency Measurement Discussion*. Retrieved July 9, 2009, from EIA: http://www.ei.doe.gov/emeu/efficiency/measure_discussion.htm	Discusses implications/difficulties of various energy efficiency measures	Discussion, no formal methodology	"Energy intensity measures are often used to measure energy efficiency and its change over time….[E]nergy-intensity measures are at best a rough surrogate for energy efficiency. This is because energy intensity may mask structural and behavioural changes that do not represent "true" efficiency improvements such as a shift away from small cars to sport-utility jeep-like vehicles" (2)
			Energy intensity: ratio of energy consumption to some measure of demand for energy services
			Indices as a measure of relative changes include (1) market-based approaches, (2) comprehensive approaches, (3) factorial decomposition approaches (Laspeyres indices: energy use is decomposed into an activity

			effect, structural effect, and an intensity effect; each measured by holding the other 2 constant), and (4) divisia index approach (may be used to decompose time trends into different factors such as structural and intensity; measure energy savings over time and uses time trend data)
			Best practice approach – difference between the current or average practice of producing and the "best practice" of production – see *Handbook on International Comparisons of Energy Efficiency in Manufacturing industry* published by the Department of Science, Technology and Society, Utrecht University in April 1998
Freeman, Scott L., Mark J. Niefer, and Joseph M. Roop. "Measuring industrial energy intensity: practical issues and problems." Energy Policy 25, no. 7-9 (1997): 703-714.	Given the available data, we examine the types of issues and problems that are likely to arise in the construction of commonly-used intensity indicators. We construct several measures of energy intensity based on alternative measures of energy use and output for several industries in order to illustrate these issues and problems.	OLS Regression; 1978-1992 US manufacturing industries. Data comes from US Standard Industrial Classification System	industrial energy intensity= energy input/industrial output (which is a economic-thermodynamic definition of efficiency)
			The higher the level of aggregation, the more desirable is the use of market value of output relative to volume of output in a measure of energy intensity. More heterogeneity of product makes it more difficult to measure output by volume.
			Energy intensity growth rates can vary greatly depending on the measure of output used. In a simple OLS regression [$\ln(Otj) = \alpha + \beta tj + vt$] with O = output for measure j; j=volume, value of production, value of shipments, or value added; Beta is annual growth rate of output measure j. "A simple t-test of the equality of the point estimate for the growth rates of output volume and each of the growth rates of value measures was calculated. The test indicated that the hypothesis of equality between the growth rate of volume of output and the growth rate of each of the value of output measures could not be rejected. Thus none of the value measures is preferred over the others by this test" (708).
			Possible causes of differences between volume and value of output: Measurement errors in price indexes - likely when there are multiple prices for a good, when an industry is composed of multiple goods, changes in data underlying industry price deflators, quality changes, and shipments and materials deflators (it is unlikely that prices of materials and products change at the same rate over time). Errors in industry specialization and coverage - difficulties occur, for example, when a single plant produces goods classified in more than one industry. Industry redefinitions - periodic redefinitions may make industry output values not strictly comparable over time.
			"The use of value-based demand indicators in an energy efficiency measure may serve to exaggerate year-to-year changes in efficiency. Among the value-based demand indicators, value added appears likely to exaggerate year-to-year changes the most" (713).
			"The trend growth rate of value of production seems to match the trend growth rate of volume of output more closely than either value of shipments or value added; we are not, however, on the basis of the statistical tests reported above, able to assert that this relationship holds with much certainty. Given that it is less likely to exaggerate swings in energy efficiency in the short run, and that it more closely matches trend growth rates than other value-based demand indicators, in the absence of serious

			coverage or specialization problems, it seems that value of production is the most desirable value-based output measure for use in an indicator of energy intensity" (713).
Liu, N., & Ang, B. (2007). Factors shaping aggregate energy intensity trend for industry: Energy intensity versus product mix. *Energy Economics*, *29*, 609-635	"The main objective of this paper is to put together the empirical results reported in [previous] studies in a coherent framework and identify possible systematic features."	Literature review	Decomposition index analysis: two commonly used indices – *Laspeyres index* and the *Divisia index*. The latter Divisia index is recommended over the former, due to its various characteristics (p. 611), and it has "emerged as the most preferred method among researchers and analysts" "Increasingly, energy efficiency performance tracking through chaining decomposition analysis has become a major application of index decomposition analysis. Index decomposition analysis is the most rigorous technique currently available to address the issues of energy efficiency performance and to track its trend at the industry-wise or economy-wide level. Lately, it has also been found useful in the development of energy efficiency indicators…" (p. 612). "In implementation, a common comment is that the kind and quality of data that are needed for a rigorous index decomposition analysis pose a far greater challenge to the analyst than issues on the choice of a decomposition method" (p. 632).
			"In developing countries… depending on the decomposition time period, there are cases where increases or decreases in the aggregate energy intensity are observed." (p. 623)
			"If what has happened in industrial countries is indicative of future developments of the developing countries, in particular the high income ones, then it would be expected that the aggregate energy intensities of these countries will likely stabilize and/or decline as a result of the impacts from energy intensity change" (p. 631)
Tanaka, Kanako. Assessing Measures of Energy Efficiency Performance and their Application in Industry. Paris: IEA, 2008.	This paper explores different measures of energy efficiency performance (hereafter referred to as "MEEP"): absolute energy consumption, energy intensity, diffusion of specific energy-saving technology and thermal efficiency.	Case study, literature review	Same functional definitions as Patterson (1993) above, except Diffusion rates of energy efficient facilities/types of equipment: "The diffusion rate indicates the rate of deployment of a specific technology which has been identified as being energy efficient. Individual technologies share some common features, including energy performance, with slight variations from one location of use to the other. The rate of diffusion of well-identified energy efficient technologies can therefore indicate progress towards enhanced energy efficiency, assuming that installation implies an actual use of the equipment" (8).
			Much the same information/conclusions as Tanaka 2008a above.

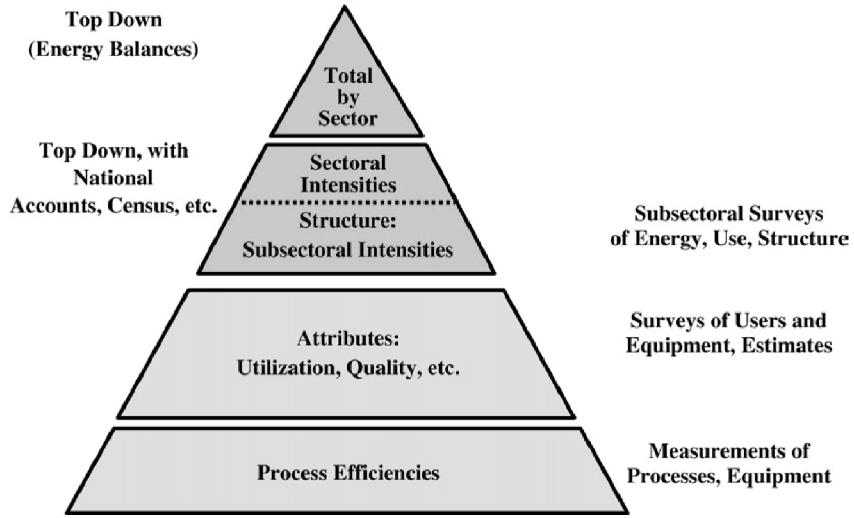
<table>
<tr>
<td>Bor, Yunchang Jeffrey. "Consistent multi-level energy efficiency indicators and their policy implications." Energy Economics 30 (2008): 2401-2419.</td>
<td>'This paper has proposed the adoption of end-use energy efficiency indices and the weighted vertical effect decomposition of changes in energy efficiency indices between upstream and downstream industries, which enable policy-makers to trace and identify those downstream industries that lead to significant changes in energy efficiency in the upstream sector.'</td>
<td>Introduction of a new EEI and case study using Taiwan’s (Republic of China) industrial sectors (1994-2003)</td>
<td>The principal function of the end-use energy efficiency indicators lies in the evaluation of the secondary energy usage performance of a nation or a sector, as well as the estimation of energy conservation potential.


Fig. 1. Pyramid concept of energy efficiency indicators source: International Energy Agency (1997).</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Economic-thermodynamic EEI:</td>
</tr>
</table>

			$E_t = A_t \sum S_{it} I_{it}$ (1) where E_t stands for the secondary energy consumption in the tth year; A_t represents the net output of activity (e.g., real GDP) in the tth year; S_{it} stands for the share of industry i in terms of the net output of activity (e.g., real GDP) $(-A_{it}/A_t)$; and I_{it} represents the economic secondary energy intensity based on the net output of activity (e.g., real GDP) $(-E_{it}/A_t)$ of industry i in the tth year[3]. By referring to the International Energy Agency (1997), the economic-thermodynamic EEI can be stipulated as follows: $\%\Delta E_{\text{efficiency}} = \frac{A_t \sum S_{it}(I_{i0} - I_{it})}{E_t}$ (2) (page 2404).
			Physical-thermodynamic EEI : energy consumption per unit of output volume; however, it is difficult to quantify the aggregated output of industrial production because such an operation meets with the problem of inconsistency, in terms of the unit of measurement for individual product outputs. One possible, though not infallible solution is to use product prices instead of volume.
			Ang (1995) proposed a multi-level method, featuring the *Divisia index*, where energy efficiency is decomposed across multiple levels of sectors in terms of changes in energy intensity and energy consumption, respectively. Benefit: reveal the existence of linkages in changes in energy efficiency indices between the upstream and downstream levels, and the same method can be used to study energy efficiency indices for industries further downstream. Problem: (i) the index is multiplicative rather than additative; (ii) the sums of the index changes in all industries at the same level do not equal the change in the index for the upstream sector level.
			The author presents an improved method of deriving an EEI, the process is, however, too complicated to adequately summarize here. 'The physical-thermodynamic EEIs developed in the present paper have two major contributions in that (i) they provide a definition and formula that are consistent with the economic-thermodynamic EEI, and (ii) they avoid the distortion of price fluctuations. Another benefit is that the EEIs can be calculated in either aggregated or disaggregated sectors' (2408).
UNDP. (2000). *World energy report: Energy and the challenge of sustainability.* New York, New York: United Nations Development Program.	Discussion of recent trends in energy intensity in both OECD and non-OECD countries	Literature and statistical review	"Per capita energy use in developing countries tends to be higher where per capita incomes are higher (in purchasing power parity terms), as in Latin America, India and Southeast Asia" (p.180)
			Trend in higher-income developing countries: "Energy demand in industry has fallen in most higher-income developing countries, both as a result of higher energy prices in the 1970s and the 1980s and open borders to international competition" (p. 180). "In recent years many manufacturers in industrialised nations have moved energy-intensive industries to developing countries, often to take advantage of cheaper labour, less stringent environmental regulation, and lower overhead and transportation costs"

			"Overall, more efficient manufacturing does not dominate the increase in ratios of primary energy to GDP in higher-income developing countries (Argentina, Brazil, India, Mexico)" (p. 181).
			Trend in lower-income developing countries: "Most of the technology used by industry in lower-income developing countries is imported from industrialized countries. Thus these industries should continue to benefit from technological improvements that promote rational energy use. While this is expected to make energy demand fall, the use of obsolete and energy-inefficient technology imported from industrialized countries will drive the specific energy demand of industry" (p. 181)
			Issues in developing countries affecting positive benefits from transfer of energy efficient technology: (1) proper technology assessment and selection, (2) adaptation and absorption capacity, (3) access to state-of-the-art technology and to capital, (4) the problems of small and medium-sized enterprises.
			There is much in this chapter on potential energy efficiency across regions (Africa p. 191), as well as obstacles/market imperfections preventing improvements, and suggested policy implications.

TABLE 6.12. ECONOMIC ENERGY EFFICIENCY POTENTIALS IN AFRICA, 2020

Sector and area	Economic potential (percent)	Country	Energy price level assumed	Base year	Source
Industry					
Total industry	15	Zimbabwe		1990	TAU, 1991
	about 30	Zambia		1995	SADC, 1996
	32	Ghana		1991	Davidson and Karekezi, 1991; Adegbulugbe, 1992a
	25	Nigeria		1985	Davidson and Karekezi, 1991; SADC, 1997
	>20	Sierra Leone		1991	Adegbulugbe, 1993
	20	Mozambique			

p. 197

World Energy Council. (2008). *Energy Efficiency Policies around the World: Review and Evaluation.* London: World Energy Council. (section 1&2 of report)	"Review of recent energy efficiency trend by world region based on a set of homogenous energy efficiency indicators covering the period 1980-2006, with a greater focus on the last sixteen years (1990-2006)"	Data comes from ENERDATA world energy database (www.enerdata.fr)	Economic ratios, also referred to as *energy intensities*, are defined as ratios between energy consumption, measured in energy units – tonnes of oil equivalent/(toe) – and indicators of economic activity, measured in monetary units at constant prices (GDP, value added, etc.)
			Techno-economic ratios are calculated at a disaggregated level by relating energy consumption to an indicator of activity measured in physical terms or to a consumption unit – also referred to as *unit consumption*
			"Since 1980, the general trend in industry in Europe, OECD Asia & Pacific, North America, China and India is a decrease in the energy required per unit of value added (industrial intensity)" (p. 25).

<table>
<tr>
<td rowspan="4">Miketa, Asami, and Peter Mulder. "Energy productivity across developed and developing countries in 10 manufacturing sectors: Patterns of growth and convergence." Energy Economics 27 (2005): 429-453.</td>
<td rowspan="4">Empirical analysis of energy-productivity convergence across 24 developed and 32 developing countries, in 10 manufacturing sectors, for the period 1971–1995</td>
<td rowspan="4">Panel regression of energy productivity at the sector level</td>
<td>Energy productivity is defined as output divided by final energy use and is thus the inverse of energy intensity.

Weighted average annual growth rates 1975 1990
<table>
<tr><th></th><th>CHE</th><th>FOD</th><th>IAS</th><th>MAC</th><th>NFM</th><th>NMM</th><th>PAP</th><th>TEX</th><th>TRM</th><th>WOD</th><th>MAN</th></tr>
<tr><td colspan="12">Relative level of energy productivity in 1990 (unweighted cross-industry average normalised to 100)</td></tr>
<tr><td>World</td><td>36</td><td>108</td><td>21</td><td>221</td><td>26</td><td>12</td><td>49</td><td>110</td><td>251</td><td>165</td><td>100</td></tr>
<tr><td colspan="12">Weighted average annual growth rate 1975–1990[a]</td></tr>
<tr><td>World</td><td>0.86</td><td>0.81</td><td>2.4</td><td>0.63</td><td>2.14</td><td>0.41</td><td>1.45</td><td>0.26</td><td>0.9</td><td>0.88</td><td>1.07</td></tr>
<tr><td>Industrialised</td><td>1.2</td><td>1.22</td><td>2.69</td><td>0.27</td><td>2.26</td><td>0.39</td><td>1.46</td><td>0.07</td><td>0.98</td><td>1.07</td><td>1.16</td></tr>
<tr><td>Rest of world</td><td>−0.84</td><td>−0.95</td><td>1.54</td><td>3.68</td><td>1.7</td><td>0.48</td><td>1.38</td><td>0.83</td><td>−3.96</td><td>−0.67</td><td>0.32</td></tr>
</table>
[a] The average is weighted with each country's 1990 share of total output per sector. The values for MAN are unweighted average of all manufacturing sectors.
(p. 434)</td>
</tr>
<tr><td>"In spite of the overall pattern of σ-convergence in nine manufacturing sectors, substantial cross-country variation in energy- productivity levels remains in existence, in particular in several energy-intensive sectors such as chemicals, iron and steel, and paper" (436).</td></tr>
<tr><td>Test for unconditional beta-convergence: where g is annual growth rate of energy productivity and y is initial level; regression w/ clustered standard errors, unbalanced sample, restricted to 1980-1990. In short, the results of our test for b-coefficient provide evidence of lagging countries catching up in terms of energy-productivity performance within most industrial sectors, though very slow convergence, up to 397 years for the wood sector. Mostly significant findings, but very low r-squared. Summarized in the large table 4.
$g_{it} = \alpha + \beta \ln(y)_{i,t-1} + \eta_t + \varepsilon_{it}$ (439).</td></tr>
<tr><td>Test for conditional beta-convergence- fixed effects regression. The results confirm the evidence of b -convergence: except for wood (WOD) in the Rest of World, all estimated b -coefficients are negative and highly significant. Moreover, the values of the R2 improved considerably, suggesting that country effects indeed play an important role, and thus making Eq. (2) a much better model for explaining energy- productivity growth across countries than Eq. (1). From the higher values of the implied in Table 5, it can be seen that allowing for country-specific effects also leads to a substantial increase in the speed of convergence. In short, our results show support for the hypothesis that, in terms of sectoral energy productivity, lagging countries tend to catch up with advanced nations, with convergence tending to be conditional on country-specific characteristics rather than unconditional or absolute.
$g_{it} = \beta \ln(y)_{i,t-1} + \mu_i + \eta_i + \varepsilon_{it}$ (441).</td></tr>
</table>

Table 6

Best and worst performance in energy productivity

CHE Country	α_i/α_{max}	FOD Country	α_i/α_{max}	IAS Country	α_i/α_{max}	MAC Country	α_i/α_{max}	NFM Country	α_i/α_{max}
1. Kuwait	(1.0)	1. Switzerland	(1.0)	1. Malaysia	(1.0)	1. Thailand	(1.0)	1. Chin. Taipei	(1.0)
2. Switzerland	(0.86)	2. Chile	(0.81)	2. Bangladesh	(0.96)	2. Belgium	(0.99)	2. S. Korea	(0.00)
3. Philippines	(0.84)	3. USA	(0.81)	3. Uruguay	(0.96)	3. Japan	(0.97)	3. Mexico	(0.95)
4. Denmark	(0.84)	4. Canada	(0.80)	4. Argentina	(0.91)	4. Austria	(0.97)	4. Austria	(0.92)
5. Greece	(0.82)	5. India	(0.79)	5. Peru	(0.86)	5. Ireland	(0.97)	5. Belgium	(0.90)
41. Mexico	(0.50)	33. Hungary	(0.45)	48. New Zealand	(0.47)	30. Colombia	(0.79)	31. Iceland	(0.62)
42. Bangladesh	(0.47)	34. Poland	(0.33)	49. Iceland	(0.45)	31. Hungary	(0.77)	32. Venezuela	(0.61)
43. USSR	(0.47)	35. Mexico	(0.33)	50. China	(0.44)	32. Poland	(0.67)	33. USSR	(0.54)
44. Trinidad	(0.47)	36. USSR	(0.27)	51. USSR	(0.40)	33. China	(0.65)	34. Bahrain	(0.49)
45. China	(0.30)	37. China	(0.20)	52. Venezuela	(0.38)	34. USSR	(0.54)	35. Ireland	(0.33)

NMM Country	α_i/α_{max}	PAP Country	α_i/α_{max}	TEX Country	α_i/α_{max}	TRM Country	α_i/α_{max}	WOD Country	α_i/α_{max}
1. Switzerland	(1.0)	1. Ireland	(1.0)	1. S. Africa	(1.0)	1. Japan	(1.0)	1. UK	(1.0)
2. France	(0.97)	2. S. Africa	(0.99)	2. N. Zealand	(0.95)	2. Italy	(0.98)	2. Belgium	(0.99)
3. Turkey	(0.94)	3. Switzerland	(0.94)	3. Belgium	(0.88)	3. Canada	(0.98)	3. Italy	(0.99)
4. Austria	(0.92)	4. N. Zealand	(0.91)	4. Finland	(0.86)	4. Finland	(0.97)	4. Slovenia	(0.99)
5. Ireland	(0.91)	5. Denmark	(0.90)	5. USA	(0.86)	5. France	(0.97)	5. Germany	(0.98)
38. Colombia	(0.59)	32. Canada	(0.63)	29. Luxembourg	(0.71)	18. Australia	(0.85)	24. Poland	(0.92)
39. USSR	(0.52)	33. Mexico	(0.62)	30. Hungary	(0.70)	19. Belgium	(0.80)	25. Turkey	(0.92)
40. China	(0.51)	34. China	(0.57)	31. India	(0.70)	20. Hungary	(0.77)	26. China	(0.90)
41. Pakistan	(0.47)	35. Poland	(0.55)	35. Colombia	(0.69)	21. Czech Rep.	(0.72)	27. USSR	(0.90)
42. Poland	(0.46)	36. USSR	(0.52)	33. China	(0.63)	22. Poland	(0.67)	28. N. Zealand	(0.89)

Relative estimated intercepts for the period 1971–1995.

The ranking of countries is based on the estimated values of μ_i from Eq. (2) in the text. The values in parenthesis denote a country's values of μ_i relative to the highest estimated value μ_{max} per sector.

(443).

To estimate the impact of energy prices, investment ratios and fuel mix on energy-productivity growth we add to the unspecified country-effects μ_i in Eq. (2), specified fixed-effects x_i, according to:

$$g_{it} = \beta \ln(y)_{i,t-1} + \sum_{j=1}^{6} \gamma_j + x_{it}^{j} + \mu_i + \eta_t + \varepsilon_{it} \quad (3)$$

with $x_{it}^1 \ldots x_{it}^6$ representing, respectively, the country-specific industrial energy price, investment ratio (i.e., the share of investment relative to output), and the share of oil, natural gas, electricity and coal in final industrial energy consumption.[13]

(page 445).

"We therefore emphasize that our analysis points to the role of country-specific factors other than prices and investment shares being crucial in determining cross-country productivity differentials."

(448).

Table 2 Causal effects of industrial energy efficiency on economic growth

Source	Purpose	Methodology	Data	Findings	Policy Implications
Wei, T. (2007). Impact of energy efficiency gains on output and energy use with Cobb-Douglas production function. *Energy Policy*, *35*, 2023-2030.	To apply the Cobb-Douglas production function to analyze the impact of energy efficiency gains on output and use	"first provides a partial equilibrium analysis… and then proceeds to an analysis on the issue in a two-sector general equilibrium system. In the latter analysis, energy price is internalized." (2023)	n/a no data, the theory is based on economy level definitions	"In short term… energy use efficiency gains will only increase non-energy output and have no effect on energy use (or production)" (2929). Energy use efficiency will lower the prices of non-energy and increase the output of non-energy goods, in the short run.	"The long term impact on energy use (or production) of energy use efficiency is far less than that of energy production efficiency. Thus on the basis of general equilibrium analysis, we conclude that measures to promote energy use efficiency is better than to promote energy production efficiency if our purpose is to limit total energy use." (2029).
				"In the GE framework, the long term impact on non-energy output and energy use of energy production (or use) efficiency is larger when compared with the short term impact. The extent depends on the elasticity parameters in the production functions." (2029) "It is also interesting to notice that energy use efficiency gains implies some increase of energy price in long term" (2029).	
				Beginning with the Cobb-Douglas PF with three primary resources K, L and E (energy): $X = aK_x^{\alpha}L_x^{\beta}(\tau E_x)^{1-\alpha-\beta}$. where X is the gross output or rough GDP. It is the technological parameter and its increase represents energy use efficiency gains. The CD function exhibits constant returns to scale. Subscript x is for input factors.	
				Short-term impacts of energy use efficiency gains: In the general equilibrium model, energy use	

				always equals energy production. Thus, Wei finds that energy use efficiency gains t have no effect on energy use: $\varepsilon_e^{s\tau} = \frac{\mathrm{d}E}{\mathrm{d}\tau}\frac{\tau}{E} = 0.$ which is a 100% rebound effect. However, *quantity of non-energy goods produced will increase and non-energy prices will decrease due to energy efficiency gains*, according to: $\varepsilon_{P_x}^{s\tau} = \frac{\mathrm{d}P_x}{\mathrm{d}\tau}\frac{\tau}{P_x} = -(1-\alpha-\beta),$	
				Long term impacts: Wei finds the elasticity of energy price in the LT to be: $\varepsilon_{P_e}^{l\tau} = \frac{\mathrm{d}P_e}{\mathrm{d}\tau}\frac{\tau}{P_e} = \frac{(1-\gamma)(1-\alpha-\beta)}{\beta+(1-\gamma)(1-\alpha-\beta)},$ *Which implies that energy use efficiency gains will increase the energy price, instead of decreasing it, in the long run. The long-term impact of t on total non-energy output is positive.*	
van Zon, A., & Yetkiner, I. H. (2003). An endogenous growth model with embodied energy-saving technical change. *Resource and Energy Economics, 25*, 81-103.	Extend the Romer model in two ways: include energy consumption of intermediates and to make intermediates become heterogeneous due to endogenous energy-saving technical change. "Our contribution to the discussion on endogenous growth then lies in the incorporation of energy as	Alteration of the Romer model addition of intermediate technologies	not relevant, the theory is abstract without empirical evidence; except the conclusion which makes policy recommenda tions exclusive to	"The paper has two important findings. First, it shows that aggregate energy efficiency may be improved through stepping up basic research. Secondly, increasing real energy prices lead to corresponding rises in the user costs of intermediates, and hence, to a fall in profits on those intermediates." (p. 85). In the case of rising growth of real energy prices, there will be less economic growth, unless policy measures are taken that counteract the negative effects on research incentives arising from a positive growth rate of real energy prices.	"We conclude that in order to have energy efficiency growth and output growth under rising real energy prices, a combination of R&D and energy policy is called for" (81). "The introduction of an energy tax in the context of the revised Romer model is not enough by itself to spur R&D efforts. Rather, these are negatively affected, because either real

	an explicit factor of production in an endogenous growth model based on Romer (1990)".		the US;	"Growth rate depends positively on the rate of embodied technical change, and that it is higher than the original growth rate in the original Romer model; the rate of growth also depends negatively on the rate of growth of real energy prices, implying that continuously rising real energy prices will tend to slow growth." (98) $K^e = KA^{(1-\alpha+\alpha\zeta)/\alpha}\left(\frac{1-\alpha}{1-\alpha+\zeta\alpha}\right)^{(1-\alpha)/\alpha}\lambda_H\left(\frac{r}{\beta}\right)^{1-\beta}\left(\frac{q}{1-\beta}\right)^{\beta-1}$ can be used to link the growth rate of output to that of real energy prices. $\hat{Y} = (1-\alpha)\hat{L}_Y + \alpha\hat{K}^e = \alpha\hat{K}^e = \hat{K} \Rightarrow \hat{Y} = \frac{1-\alpha+\zeta\alpha}{1-\alpha}\hat{A} - \frac{\alpha(1-\beta)}{1-\alpha}\hat{q} = \hat{K}$ The steady state growth rate is given by: Which implies that with continuous rises in real energy prices (q > 0), a more intensive use of raw capital as a substitute for energy is called for. Moreover, the higher the effective capital elasticity of energy (i.e. 1 − β) is, the stronger will be the decrease in the growth rate of output for a given growth rate of real energy prices.	energy price changes or the introduction of a tax lowers the present value of a blueprint, which in turn reduces the value marginal product of research labour. In that case, we would expect a decrease in the allocation of labour to R&D. However, the subsidy on wage cost in the R&D sector can actually more than compensate the fall in the value marginal product of R&D labour through the fall in profit flows, so that in this case, we could observe faster growth than before the tax." (98).
Ockwell, D. (2008). Energy and economic growth: Grounding our understanding in physical reality. *Energy Policy* , *36*, 4600-4604.	This review provides an overview of our current understanding of the relationship between energy use and economic growth. Findings are analyzed with respect to an assumed goal of reducing emissions.		USA; literature review with an interest in economy wide results	"Sustained economic growth is a mantra for governments worldwide and is seen as having a key role to play in poverty alleviation. But economic activity is predominantly linked to the use of energy, principally from fossil fuels, which account for over 60% of global greenhouse gas emissions. This implies an urgent need to decouple economic growth from energy use." (4600) "For ecological economists, energy is a fundamental factor enabling economic production. Some commentators even argue that energy availability actually drives economic	"The ecological economics worldview and some of the supporting empirical evidence suggests that the extent to which it is possible to decouple energy use from economic growth may be more limited than has previously been assumed. This implies a need to focus on decarbonising energy supplies, as opposed to focusing solely on developing and deploying energy-efficient

				growth, as opposed to economic growth resulting in increased energy use (e.g. Cleveland et al., 1984). From this perspective, the possibility of decoupling energy use from economic growth seems more limited." (4601)	technologies"
				"There is a distinct and unresolved divide between neo-classical and ecological economists as to how to treat the contribution of energy to economic growth, with ecological economists arguing that the non-classical worldview fails to account for the physical limits implied by the laws of thermodynamics. If the ecological economics worldview holds, the potential for decoupling energy from economic growth may be limited." (4603).	"Sufficient empirical evidence does not yet exist to provide conclusive support for the claims of either the ecological or neo-classical schools of thought. Breaking down the evidence that does exist suggests that observed improvements in GDP/energy use ratios may be better explained by shifts towards higher quality fuels than by improvements in the energy efficiency of technologies." (4604)
				"Direct rebound effects for household energy services in OECD countries are likely to be less than 30%. But they could be larger for producers and potentially much larger in developing countries." (4603)	

Akinlo, A. E. (2008). Energy consumption and economic growth: Evidence from 11 Sub-Saharan African countries. *Energy Economics*, *30*, 2391-2400.	"…the objective of the paper is to investigate the cointegration and causality relationships between energy consumption and income using ARDL bounds test and the Granger causality (GC) test based on vector error correction model (VECM)." (2392)	Cameroon, Cote D'Ivoire, Congo, Gambia, Ghana, Kenya, Nigeria, Senegal, Sudan, Togo and Zimbabwe. For the period 1980–2003 Uses macro-level data for energy use and economic growth	Granger causality test based on vector error correction model (VECM) shows bi-directional relationship between energy consumption and economic growth for Gambia, Ghana and Senegal. However, Granger causality test shows that economic growth Granger causes energy consumption in Sudan and Zimbabwe. The neutrality hypothesis is confirmed in respect of Cameroon and Cote D'Ivoire. The same result of no causality was found for Nigeria, Kenya and Togo.	The result shows that each country should formulate appropriate energy conservation policies taking into cognizance of her peculiar condition.
			Gambia, Ghana and Senegal, there is bidirectional relationship between energy consumption and economic growth. This finding seems to support Glasure and Lee (1997) result for Republic of Korea and Singapore.	"The implication of this finding is that a high level of economic growth leads to high level of energy demand and vice-versa. This means that investment and other efficient measures that increase energy supply can be implemented, but such measures should not be at the expense of the environment. Indeed, in order not to adversely affect economic growth, energy conservation policies that aim at reducing energy must rather find ways of reducing consumer demand [for energy]. This sort of policy could be achieved through an appropriate mix of energy taxes and subsidies."
			With respect to Sudan and Zimbabwe, the Wald test statistics that fall below the critical F values shows that the null hypothesis that energy consumption do not Granger cause economic growth in the short run has been accepted.	The unidirectional causality running from economic growth to energy consumption may statistically suggest that energy consumption measures may be taken without jeopardizing

					economic development. This is not to suggest however, that energy consumption level should be reduced. The option therefore might be for these countries to enhance the level of efficiency in the energy sector. " (2396)
				In the case of Cameroon and Cote D'Ivoire, the evidence suggests no causality in both directions supporting the so called 'neutrality hypothesis'.	This would imply that energy conservation policies do not affect economic growth
				The result indicates a unidirectional relationship between energy consumption and economic growth for Congo. The causality runs from economic growth to energy consumption. In Nigeria, Kenya and Togo, no evidence of causality in either direction is found i.e. 'neutrality hypothesis'.	Theoretically, for these countries energy conservation may be pursued without serious adverse effect on economic growth
					No evidence was found of a unidirectional causal effect from energy consumption to growth.
Mishra, V., Smyth, R., & Sharma, S. (2009). The energy-GDP nexus: Evidence from a panel of Pacific Island countries. *Resource and Energy Economics , 31*, 210-220.	To test direction of causality between energy consumption and GDP, all at the aggregated, country, level.	Granger causality test	Panel of nine PICs (Fiji, French Polynesia, Kiribati, New Caledonia, Papua New Guinea, Samoa, Solomon Islands, Tonga and Vanuatu)	"If there is unidirectional Granger causality running from GDP to energy consumption or no Granger causality in either direction, it may be implied that energy conservation policies have little or no adverse effect on economic growth. On the other hand, if unidirectional Granger causality runs from energy consumption to GDP, it follows that reducing energy consumption could lead to a fall in income, while increases in energy consumption could contribute to high rates of economic growth in the PICs. " (212)	'As Mehrara (2007, p. 2940) states, ''when it comes to whether energy use is a result of, or a perquisite for, economic growth, there are no clear trends in the literature. Depending on the methodology, used, and country and time period studied, the direction of causality between energy consumption and economic variables has remained empirically elusive and

			over the period 1980–2005. Energy and GDP per capita are the data of interest and use		controversial’’.’ (212)
				“The main finding in terms of the energy-GDP nexus is that there is bidirectional Granger causality between energy consumption and GDP and that for the panel as a whole energy consumption and GDP have a positive effect on each other. A 1% increase in energy consumption increases GDP by 0.11%, while a 1% increase in GDP increases energy consumption by 0.23%. Bidirectional Granger causality implies that energy consumption and economic growth are jointly determined and affected at the same time. “ (219)	
				“To this point, there are few studies that examine the relationship between energy consumption and GDP at a disaggregated level and no such panel-based studies. It would be difficult to obtain disaggregated data on energy consumption for a panel of PICs…” (219)	

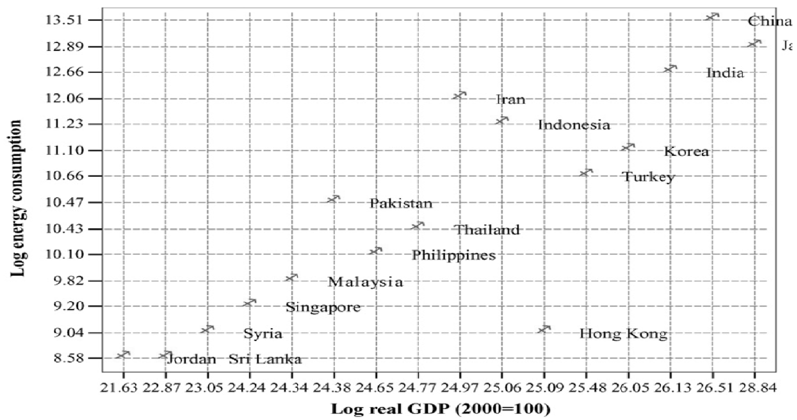
Lee, C.-C., & Chang, C.-P. (2008). Energy consumption and economic growth in Asian economies: A more comprehensive analysis using panel data. *Resource and Energy Economics , 30,* 50-65.	The purpose is to "empirically examine long-run co-movement and the causal relationship between energy consumption and real GDP. It does so based on the aggregate production function."	Panel unit root tests and heterogeneous panel cointegration tests, and a Granger causality test compares the relationship between energy consumption and real GDP while controlling for capital and labor input in Asian economic groups rather than individual countries	16 Asian economies from 1971 to 2002 Aggregated data at the national level is used. China, Hong Kong, India, Indonesia, Iran, Japan, Jordan, Republic of Korea, Malaysia, Pakistan, the Philippines, Singapore, Sri Lanka, the Syrian Arab Republic, Thailand and Turkey	 Fig. 1. Plots of real GDP and energy consumption (in log). $GDP_{it} = \alpha_i - \delta_i t + \gamma_{1i}EC_{it} - \gamma_{2i}LB_{it} + \gamma_{3i}K_{it} + \varepsilon_{it},$ They use a Cobb-Douglas production function, where EC = Ln(energy consumption), LB = Ln(L), K = Ln(Capital stock), and GDP = Ln(Y) When estimated with a fully modified OLS, accounting for time and fixed effects, "all of the coefficients of EC, LB and K are statistically significant at the 5% level, and the effect is positive. Implicit here is that a 1% increase in energy consumption leads to a 0.32% increase in real GDP in our sample of Asian economies."

Table 4
Fully modified OLS estimates

Country groupings	EC	LB	K
China	−0.77 (−2.99)**	2.03 (4.63)**	0.86 (14.42)**
Hong Kong	0.51 (4.48)**	0.73 (1.74)*	0.26 (1.94)*
India	0.94 (3.85)**	−0.37 (−0.77)	0.43 (4.97)**
Indonesia	0.51 (3.98)**	0.71 (3.00)**	0.21 (11.32)**
Iran	0.71 (1.69)*	−0.76 (−1.00)	0.39 (3.87)**
Japan	−0.14 (−0.65)	2.85 (5.70)**	0.33 (3.11)**
Jordan	0.67 (5.69)**	0.06 (0.53)	−0.01 (−0.10)
Korea	0.62 (4.32)**	0.88 (2.00)**	0.00 (0.04)
Malaysia	0.26 (1.41)	1.01 (2.79)**	0.16 (2.94)**
Pakistan	0.63 (6.37)**	0.37 (2.65)**	0.29 (7.64)**
Philippines	−0.06 (−0.42)	0.82 (5.00)**	0.28 (6.37)**
Singapore	0.30 (3.67)**	1.33 (5.57)**	0.13 (1.32)
Sri Lanka	−0.08 (−0.74)	2.15 (14.50)**	0.08 (4.03)**
Syrian	0.03 (0.31)	1.02 (7.82)**	0.15 (2.56)**
Thailand	0.47 (15.07)**	1.31 (14.37)**	0.14 (7.34)**
Turkey	0.57 (8.24)**	0.26 (3.15)**	0.19 (12.24)**
Panel	0.32 (13.57)**	0.90 (17.92)**	0.24 (21.01)**

Notes: *t*-Values are in parentheses. ** and * indicate statistical significance at the 5% and 10% level, respectively.

				"On the basis of the short-run and long-run dynamics of energy consumption and GDP, as concerns the energy-income relationship in these Asian economies, we refute the neutrality hypothesis that has previously been advanced. Energy consumption is found to Granger cause GDP in the long-run, but not vice versa. There is no short-run or long-run causal relationship running from GDP to EC." (63)	
World Bank. (2006). *Improving Lives: World Bank Group Progress on Renewable Energy and Energy Efficiency Fiscal Year 2006.* Washington DC: The World Bank Group.	Review purpose and success of WBG projects dealing with energy efficiency – however aside from generalizations about benefits of greater efficiency, no specific attention to industry is given.	Discussion, review of past projects	Developing countries; sectoral (residential) energy efficiency definitions	"Energy price volatility, supply uncertainties, and environmental concerns are leading many countries to give greater consideration to alternatives such as renewable energy and energy efficiency that can provide affordable energy services and enhance energy security and reliability in an environmentally sustainable manner." (page 7)	All policy implications are discussed with reference to household level efficiency improvements, not industry.
				The energy efficiency potential of developing countries remains largely untapped.	
				Bonn target – WBG adopted a target of a 20% average annual growth in energy efficiency and new renewable energy commitments between fiscal years 2005 and 2009	

				"The energy security of countries can be enhanced in many ways with the help of renewable energy and energy efficiency, including by diversifying fuels used and the sources from which they come, enhancing availability by increasing supply and demand-side energy efficiency, reducing energy infrastructure vulnerability through the use of distributed energy, and promoting good governance and equitable energy sector rent distribution to reduce political and social divisions." (8)	
UNDP-Kenya. (2006). *Investors guide to energy efficiency*. Nairobi: United Nations Development Programme.	Discussion of benefits and best practices regarding energy efficiency investments, focus on industry	None… discussion only	Kenya; data is anecdotal	Benefits of energy efficiency: "At the national level it improves economic competitiveness, reduces the country's import bill, improves the balance of trade, creates jobs, and thereby reduces poverty. It also improves security of energy supply, a matter of particular interest to Kenya which imports all her petroleum requirements." (page 5)	Industries with the highest potential for benefits from improved efficiency: Iron and steel processing; Chemicals processing; Petroleum refining; Pulp and paper manufacturing; and Cement manufacturing.
				"The industrial and commercial sectors in Kenya are genuinely concerned that the high cost of energy erodes the competitiveness of their products in the local, regional and international markets. Effective energy efficiency measures would result in lower production costs of goods and services and thus improved competitiveness of Kenyan products, higher productivity, increased profits, good prospects for new capacity investment and general strengthening of the manufacturing sector. This would also be reflected in increased job opportunities and generally improved economic activities within the country. Energy efficiency would, moreover, reduce overall demand for energy and thereby defer capital investments needed to provide additional energy supplies. " (5)	Much of Kenyan industry is characterized by "antiquated machinery." "**Energy Audits**" are required to determine best policy or method to improve efficiency. An "energy audit" may be in the form of analysis of historical data, screening & survey, or detailed investigation and analysis.

Stern, D. I., & Cleveland, C. J. (2004). *Energy and Economic Growth*. Rensselaer Polytechnic Institute. Troy: Rensselaer Working Papers in Economics.	This paper reviews the relevant biophysical theory, models of growth, the critiques of models, and the various mechanisms that can weaken the links between energy and growth.	This paper ***surveys the literature*** on the effect of changes in energy supply on economic growth in general in both *developing and developed countries*. *Very little dealt directly with energy efficiency and/or industry*.		"The first law of thermodynamics (the conservation law) implies the mass-balance principle (Ayres and Kneese, 1969). In order to obtain a given material output greater or equal quantities of matter must be used as inputs with the residual a pollutant or waste product. Therefore, there are minimal material input requirements for any production process producing material outputs. The second law of thermodynamics (the efficiency law) implies that a minimum quantity of energy is required to carry out the transformation of matter. All production involves the transformation or movement of matter in some way. Some form of matter must be moved or transformed though particular elements and chemicals may be substitutable. Therefore there must be limits to the substitution of other factors of production for energy. All economic processes must, therefore, require energy, so that energy is always an essential factor of production (Stern, 1997a). " (page 4)	
				"Howarth (1997) argues persuasively that the rebound effect is less than the initial innovation induced reduction in energy use, so improvements in energy efficiency do, in fact, reduce total energy demand. " (21-22).	
UNDP. (2000). *World Energy Assessment.* New York, NY, USA: United Nations Development Programme.	Relevant discussion to **energy security** concerns	Various	Global Economy and sectoral data	"Energy is similarly indispensable for continued human development and economic growth. Providing adequate, affordable energy is essential for eradicating poverty, improving human welfare, and raising living standards worldwide. And without economic growth, it will be difficult to address environmental challenges, especially those associated with poverty. " (31)	Thus poverty alleviation in developing countries should involve the energy strategy of universal access to adequate, affordable, reliable, high-quality, safe, and environmentally benign modern energy services, particularly for cooking, lighting, income generation, and transport. " (59)
				"In Africa per capita energy use has barely increased since 1970 and remains at less than 10 percent of per capita use in North America (annex table C2). The same is true for Asia despite a near-doubling in per capita energy use since 1970. In essence this means that most Africans and Asians have no access to commercial energy. Latin America saw little improvement, while China and especially the Middle East made above-average progress in providing access to modern energy services." (33)	
				"The link between energy use and economic activity is neither static nor uniform across regions. In the past, energy and economic development were closely related. But this relationship does not necessarily hold at higher levels of economic development. During 1960–78 changes in primary energy use and GDP grew at the same rate in OECD countries (figure 1.1). Thereafter, a change in elasticity between	

				energy and economic activity suggests that the often-postulated one-to-one relationship between primary energy use and economic activity can be changed, at least temporarily. Because of its versatility, convenience, cleanliness (at point of use), and productivity-enhancing features, the increase in electricity use has outpaced GDP growth in all regions—often by a large margin. In addition, the efficiency of converting electricity from final energy to energy services is the highest of all fuels. " (34)	
				It appears that economies are more sensitive to price changes than to price levels	
				"Energy security—the continuous availability of energy in varied forms, in sufficient quantities, and at reasonable prices—has several aspects. It means limited vulnerability to transient or longer disruptions of imported supplies. It also means the availability of local and imported resources to meet growing demand over time and at reasonable prices" (112)	
				Energy insecurity and shortages affect countries in two ways: they handicap productive activities, and they undermine consumer welfare. Energy insecurity discourages investors by threatening production and increasing costs. Shortages in electricity supplies (as in many developing countries) require more investment for on-site electricity production or standby supplies. For small investors, the cost of operation is increased, since electricity from private small-scale generation is more expensive than public national supplies (113)	
				"For any economy, an unreliable energy supply results in both short- and long-term costs. The costs are measured in terms of loss of welfare and production, and the adjustments that consumers (such as firms) facing unreliable fuel and electric power supplies undertake to mitigate their losses. Interruptions in supply may trigger loss of production, costs related to product spoilage, and damage to equipment. The extent of these direct economic costs depends on a host of factors, such as advance notification, duration of the interruption, and timing of the interruption, which relates to the time of day or season and to the prevailing market conditions and demand for the firm's output. These direct costs can be very high. In addition, the economy is affected indirectly because of the secondary costs that arise from the interdependence between one firm's output and another firm's input. " (113)	
Taylor, R., Govindarajalu, C., Levin, J., Meyer, A. S., & Ward, W. A. (2008). *Financing Energy Efficiency: Lessons*	This book reviews the reasons for the success or failure of a range of recent energy efficiency programs in developing countries and economies in transition.	Review of projects' success and failures	Brazil, China, India and developing nations as a bloc.	"In the world as a whole, but especially in these rapidly growing developing countries, efficiency improvements to generate more economic output with less energy input is essential for reasons of energy supply security, economic competitiveness, improvement in	"The challenge for governments in this case is to influence the broad technology choice decisions of investors and encourage them to adopt energy efficiency solutions.

from Brazil, China, India and Beyond. Washington DC: The World Bank Group.			Economy level energy use.	livelihoods, and environmental sustainability.“ (3)	The main tools that governments can use to intervene here are policy“ (4)
				“Eighty percent of the world’s economic growth during 2004–30 is expected to occur in the non-OECD countries. As the developing countries seek to gain at least a modest level of prosperity, their energy demand is expected to almost double in the IEA Reference Scenario, adding 4.2 btoe to global demand” (24)	
				“In addition to the mobilization of resources to meet rising energy demand, a leading concern of most countries is ensuring their security of energy supply. Most countries are net energy importers, and rely on energy trade to obtain the mix of new energy sources needed, affecting their trade balances. A related concern is the prospect of sharp price increases and overall volatility in energy costs, stemming from tightening supply and potential disruptions in delivery.” (26)	
Sorrell, S., & Dimitropoulos, J. (2008). The rebound effect: Microeconomic definitions, limitations and extensions. *Ecological Economics* , *65*, 636-649.	This paper examines the definition and measurement of the direct rebound effect for individual energy services. Indirect and economy-wide effects are not discussed. The focus throughout is on energy efficiency improvements in consumer goods.	Literature review	Universal definitions are the focus, with some anecdotal references to the US	Direct rebound effects: “Improved energy efficiency for a particular energy service will decrease the effective price of that service and should therefore lead to an increase in consumption of that service. This will tend to offset the reduction in energy consumption provided by the efficiency improvement” (637)	“The policy implication is that non-price regulations to improve energy efficiency may neither reduce energy demand nor help to mitigate climate change.” (637)
				Indirect effects: “The lower effective price of the energy service may lead to changes in the demand for other goods, services, and factors of production that also require energy for their provision. For example, the cost savings obtained from a more efficient central heating system may be put towards an overseas holiday” (637)	

				Economy wide effects: "A fall in the real price of energy services may reduce the price of intermediate and final goods throughout the economy, leading to a series of price and quantity adjustments, with energy-intensive goods and sectors likely to gain at the expense of less energy-intensive ones."	
Sorrell, S. (2009). Jevons' Paradox revisited: The evidence for backfire from improved energy efficiency. *Energy Policy* , *37*, 2310-2317.	"While the evidence remains ambiguous, the central argument is that energy—and by implication improved energy efficiency—plays a significantly more important role in economic growth than is assumed within mainstream economics. " (1457)	Literature review/critique	Global or n/a. macro level focus.	"Since energy-efficiency improvements reduce the marginal cost of energy services such as travel, the consumption of those services may be expected to increase. This increased consumption of energy services may be expected to offset some or all of the predicted reduction in energy consumption. " (1457) **Box 1**–Indirect rebound effects. *Embodied energy effects*: The equipment used to improve energy efficiency (e.g. thermal insulation) will itself require energy to manufacture and install and this 'embodied' energy consumption will offset some of the energy savings achieved. *Re-spending effects*: Consumers may use the cost savings from energy-efficiency improvements to purchase other goods and services which themselves require energy to provide. As an extreme example, the cost savings from a more energy-efficient central heating system may be put towards an overseas holiday, leading to an increase in kerosene consumption. *Output effects*: Producers may use the cost savings from energy-efficiency improvements to increase output, thereby increasing consumption of capital, labour and materials which themselves require energy to provide. If the energy-efficiency improvements are sector wide, they may lead to lower product prices, increased consumption of the relevant products and further increases in energy consumption. All such improvements increase the overall productivity of the economy, thereby encouraging economic growth, increased consumption of goods and services and increased energy consumption. *Energy market effects*: Large-scale reductions in energy demand may translate into lower energy prices which will encourage energy consumption to increase. The reduction in energy prices will also increase real income, thereby encouraging investment and generating an extra stimulus to aggregate output and energy use. *Composition effects*: Both the energy-efficiency improvements and the associated reductions in energy prices will reduce the cost of energy-intensive goods and services to a greater extent than non-energy-intensive goods and services, thereby encouraging consumer demand to shift towards the former. (page 1457)	

<table>
<tr>
<td rowspan="4"></td>
<td rowspan="4"></td>
<td rowspan="2"></td>
<td colspan="3">
Box 2–Defining energy efficiency.

Energy efficiency may be defined as the ratio of useful outputs to energy inputs for a system. The system in question may be an individual energy conversion device (e.g. a boiler), a building, an industrial process, a firm, a sector or an entire economy. In all cases, the measure of energy efficiency will depend upon how 'useful' is defined and how inputs and outputs are measured (Patterson, 1996). The options include:
Thermodynamic measures: where the outputs are defined in terms of either heat content or the capacity to perform useful work;
Physical measures: where the outputs are defined in physical terms, such as vehicle kilometres or tonnes of steel; or
Economic measures: where the outputs (and sometimes also the inputs) are defined in economic terms, such as value-added or GDP.
When outputs are measured in thermodynamic or physical terms, the term energy efficiency tends to be used, but when outputs are measured in economic terms it is more common to use the term 'energy productivity'. The inverse of both measures is termed 'energy intensity'. The choice of measures for inputs and outputs, the appropriate system boundaries and the timeframe under consideration can vary widely from one study to another. However, physical and economic measures of energy efficiency tend to be influenced by a greater range of variables than thermodynamic measures, as do measures appropriate to wider system boundaries. Hence, the indicator that is furthest from a thermodynamic measure of energy efficiency is the ratio of GDP to total primary energy consumption within a national economy.
Economists are primarily interested in energy-efficiency improvements that are consistent with the best use of all economic resources. These are conventionally divided into two categories: those that are associated with improvements in overall, or 'total factor' productivity ('technical change'), and those that are not ('substitution'). The latter is assumed to be induced by changes in the price of energy relative to other inputs. The consequences of technical change are of particular interest, since this contributes to the growth in economic output. However, distinguishing empirically between these two categories can be challenging, not least because changes in relative prices also induce technical change.

(page 1459)
</td>
</tr>
<tr>
<td></td>
<td>"While many studies demonstrate strong correlations between economic output and energy consumption, the extent to which the growth in economic output can be considered a cause of the increased energy consumption, or vice versa, remains unclear. " (1460)</td>
<td rowspan="3">"This review suggests several possible avenues for research, which may supplement attempts to quantify rebound effects. First, econometric and decomposition techniques could be used to better understand the source of changes in aggregate energy efficiency (e.g. the relative contribution of structural change, technical change, input substitution, changes in fuel mix and other factors) (Sue Wing, 2008). Second, these techniques could also be used to investigate the extent to</td>
</tr>
<tr>
<td></td>
<td></td>
<td>"The conventional wisdom (as represented by both neoclassical and 'endogenous' growth theory) is that increases in energy inputs play a relatively minor role in economic growth, largely because energy accounts for a relatively small share of total costs" (1460)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>"This view has been contested by ecological economists, who argue instead that the increased availability of 'high quality' energy inputs has been the primary driver of economic growth over the last two centuries" (1460)</td>
</tr>
</table>

				"Cleveland et al. (1984) claim that a strong link exists between *quality adjusted* energy use and economic output and this link will continue to exist, both temporally and cross-sectionally. This contrasts with the conventional wisdom that energy consumption has been 'decoupled' from economic growth. They also claim that a large component of increased labour productivity over the past 70 years has resulted from empowering workers with increased quantities of energy, both directly and indirectly as embodied in capital equipment and technology. This contrasts with the conventional wisdom that productivity improvements have resulted from technical change. Other ecological economists argue that the productivity of energy inputs is substantially greater than the share of energy in total costs – again in contradiction to the conventional wisdom."	which different types of energy efficiency improvement are associated with improvements in the productivity of other inputs and with improvements in total factor productivity." (1468)
				"…if increases in energy inputs contribute disproportionately to total factor productivity improvements and economic growth, then improvements in thermodynamic efficiency may do the same. Conversely, if increases in energy inputs contribute little to productivity improvements and economic growth, then neither should improvements in thermodynamic efficiency."	
Madlener, R., & Alcott, B. (2009). Energy Rebound and Economic Growth: A review of the main issues and research needs. *Energy* , *34* (4), 370-76.	"This paper summarises some of the discussions around the rebound effect, puts it into perspective to economic growth, and provides some insights at the end that can guide future empirical research on the rebound topic. " (1)	Summary of existing debates/ studies	Economy level focus	"A commonly found argument in standard growth theory literature is that technical change and factor substitution can effectively de-couple economic growth from the demand for resources and environmental services" (7). "Energy efficiency, as part of the technical progress in neo-classical growth theory, is conventionally seen as a driver of economic growth" (7). "A further development of endogenous growth	"Increases in energy efficiency are no panacea for either energy conservation or economic growth and welfare; demand saturation and substitutability of input factors matter a great deal, and both of them change over time, as do our needs and wants." (p. 9)

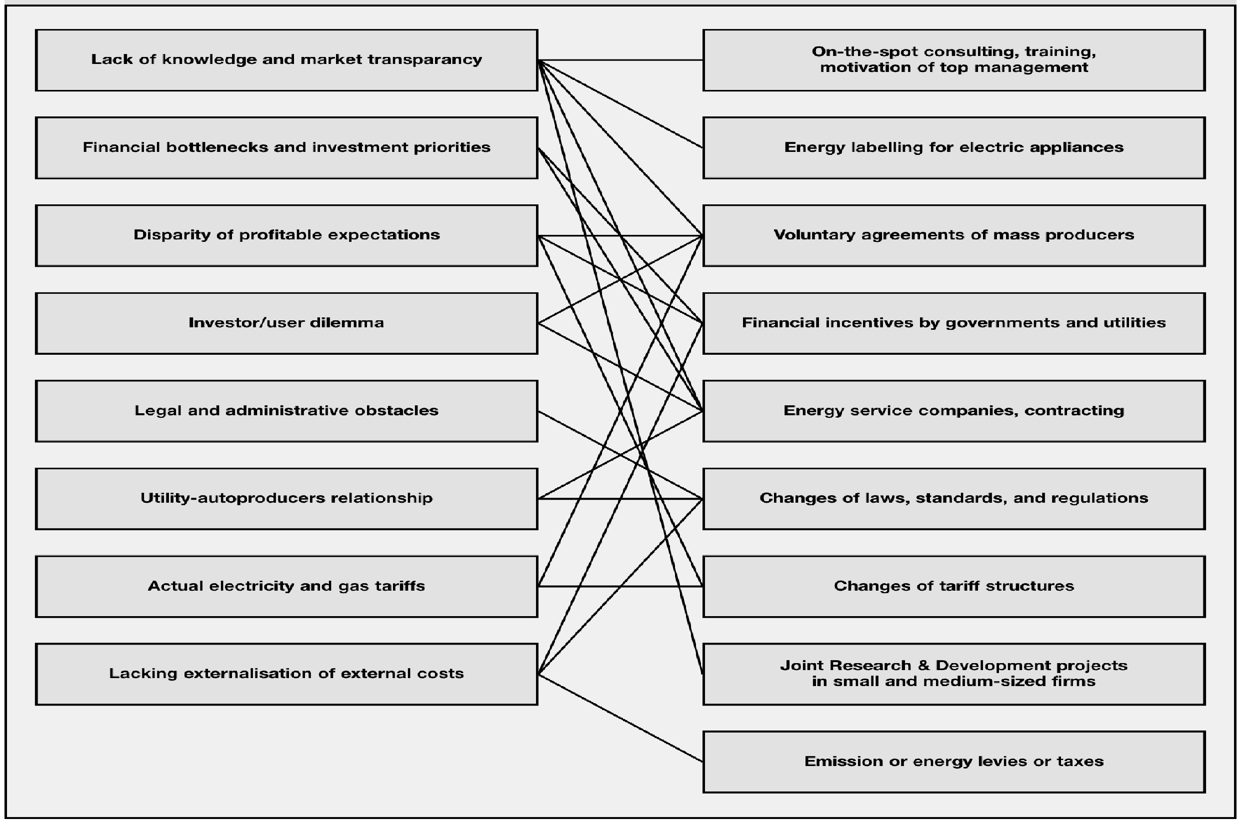
				models to also account for rebound effects renders hope that in the future the relationship between economic growth, technical change and resource use (and eventually the size of various rebound effects on the macroeconomic level) can be better modeled and understood.”	
Lovins, A. (2005, September). More profit with less carbon. *Scientific American* , 74-82.	Advocating greater efficiency as a key to both econ growth and lower carbon, seeks to clarify some misconceptions.	Non theoretic discussion	USA; data is at sectoral or national level	”These sharp-penciled firms, and dozens like them, know that energy efficiency improves the bottom line and yields even more valuable side benefits: higher quality and reliability in energy efficient factories, 6 to 16% higher labour productivity in efficient offices, and 40 percent higher sales in stores skilfully designed to be illuminated primarily by daylight.	
				These savings act like a huge universal tax cut that also reduces the federal deficit. Far from dampening global development, lower energy bills accelerate it.	
				The greatest opportunities, though, are in developing countries, which are on average three times less efficient than the U.S.” (7)	

Table 3 Barriers to entry of technologies and best practices for policymaking

Source	Purpose	Data/focus of study	Barriers to industrial implementation of efficient technologies	Policy solutions
Reddy, A. K. (1991). Barriers to improvements in energy efficiency. *Energy Policy , 19* (10), 953-961.	"…to create a typology of the possible barriers to energy-efficiency improvements, to explore their origin and to suggest measures that, by themselves or in conjunction with other measures, will surmount them."	Based on experience in India	Ignorance of available tech improvements	Provide information in various ways, train consumers (households and industry, all energy-users).
			Poor and/or first-cost sensitive	Convert the initial down-payment into a payments stream that coincides in time with the savings stream; innovative financing
			Indifference to energy costs in equipment purchases	Imperative government intervention. Realistic pricing, regulate appliances/machinery responsible for poor energy efficiencies, and energy rationing are possible solutions.
			Helpless/inability to install and maintain new equipment	Necessary to nurture an efficiency-improvement industry to "provide consumers with the expertise in the form of total hardware plus software packages" (954).
			Uncertainty about energy prices	Stabilize or "slowly change energy prices over the long term and/or financing the investments and recovery at a guaranteed rate" (954).
			Inherited inefficient machinery/ indirect purchase decisions (often where burden of capital investment falls on builder/landlord and paying of bills rests with owner/tenant)	Labelling equipment with energy performance to provide better information to all parties
			Lack of end-use efficient equipment availability – manufacturers may fail to produce if greater efficiency actually reduces revenue/sales	Enforced efficiency standards and labelling of equipment. Also, legal approvals and financing that is dependent on energy efficiency and standards can help.
			Uninterested government (particularly a problem in developing countries)	Popularize energy efficiency development strategy; create public pressure "do dismantle this barrier" (957).

			Skills-short government	Implement extensive and intensive training programs
			Government without adequate training facilities	"…special programmes to develop the required training facilities and to build up a cadre of trainers." "…represents an opportunity for collaboration both with other developing and industrialized countries." (957).
			Government without access to hardware and software	Provide "access through continuously updated menus of technologies for a particular energy service as well as menus of policies to implement an improvement in a particular service" (958).
			Capital-short government of an infrastructure-poor country	"this barrier has to be tackled by international aid and funding agencies in the same way as in the case of poor and first-cost sensitive consumers: the first costs must be converted through loans or aid into operating costs"(958).
			Powerless energy-efficiency agency	Locate "energy-efficiency agency outside and above the energy system and under a sufficiently high political authority to ensure that required measures are implemented across all sectors and entities" (958).
			Cost-blind price-fixer –"energy prices in developing countries seldom reflect real costs of generating energy and the true costs to society"	Move "towards long-run marginal cost pricing and by ensuring that efficiency improvements are implemented along with price increases" (958).
			Fragmented decision-maker	Ensure " that efficiency improvements are made part of the same investment decision as energy supply expansion and that they are made in the same office by the same decision-maker. Also, efficiency improvements should be included in the least-cost planning process" (958).
			Inefficient-technology exporter – developing countries	"…assistance with technology assessment, by

			depend on importing less-efficient technologies from developed countries	favouring energy-efficient technologies in aid programmes and by supporting technological leap-frogging in developing countries" (959).
			Supply-biased international assistance	Development must be measured by the level of energy services not the magnitude of energy consumption. Also, requires including efficiency improvements in the list of options for providing services and pursuing least-cost planning.
			Four criteria that must be satisfied by a successful large-scale programme that seeks to capture the full economic potential: • it deals with the high consumer discount rate problem • it is profitable for the companies involved • it can avoid penalizing non-participants • it can ensure that estimated savings are close to actual savings Promoting innovation rather than efficiency is also an effective way to improve energy efficiency.	
UNDP. (2000). *World Energy Assessment.* New York, NY, USA: United Nations Development Programme.		P. 206: Obstacles and Market Imperfections for Energy Efficiency and Related Policies: A scheme for Policy Options and Integrated Efficiency Policy (In general, not restricted to Industrial efficiency)		

<table>
<tr><td></td><td></td><td colspan="3">
</td></tr>
<tr><td></td><td></td><td></td><td>“But in practice, many obstacles and market imperfections prevent profitable energy efficiency from being fully realised (Jochem and Gruber, 1990; Hirst, 1991; IEA, 1997a; Gardner and Stern, 1996; Reddy, 1991)” (200).</td><td>“Obstacles to end-use efficiency vary by country for many reasons, including technical education and training, entrepreneurial and household traditions, the availability of capital, and existing legislation. Market imperfections include the external costs of energy use (Hohmeyer, Ottinger, and Rennings, 1997) as well as subsidies, traditional legislation and rules, and traditions, motivations, and decision-</td></tr>
</table>

				making in households, companies, and administrations. Finally, an inherent obstacle is the fact that most energy efficiency investments remain invisible and do not contribute to politicians' public image. The invisibility of energy efficiency measures (in contrast to photovoltaic or solar thermal collectors) and the difficulty of demonstrating and quantifying their impacts are also important. Aspects of social prestige influence the decisions on efficiency of private households—as when buying large cars (Sanstad and Howarth, 1994; Johchem, Sathave, and Bouille, 2000)." (200).
McKane, A., Price, L., & de la Rue du Can, S. (2007). Policies for Promoting Industrial Energy Efficiency in Developing Countries and Transition Economies. *Background Paper for the UNIDO Side Event on Sustainable Industrial Development* (pp. 1-87). Vienna: UNIDO. This paper presents a portfolio of policy options under the organizing structure of the Industrial Standards Framework			"Energy-intensive industries account for more than half of the industrial sector's energy consumption in many developing countries (Dasgupta and Roy, 2000; IEA, 2003a; IEA, 2003b)" (9).	The Industrial Standards Framework proposes a link between ISO 9000/14000 quality and environmental management systems and industrial energy efficiency. Industrial standards framework includes: target-setting agreements, an energy management standard, system optimization training and tools, capacity building to create system optimization experts, now and in the future, a System Optimization Library to document and sustain energy efficiency gains, and tax incentives and recognition. In addition, the Framework could accommodate: standardized system optimization methodologies certification of energy efficiency projects for trading energy efficiency credits The purpose of the Framework is to introduce a standardized and transparent methodology into industrial energy efficiency projects and practices; and builds on existing knowledge of best practices.
			"The disappointing results from these misapplications can provide a serious disincentive for any subsequent effort to achieve greater energy efficiency" (6).	
			"The key to effective industrial energy efficiency policy is consistency, transparency, engagement of industry in program design and implementation, and, most importantly, allowance for flexibility of industry response" (2).	
			Some reasons for investment in energy efficiency: Cost reduction; Improved operational reliability and control; Improved product quality; Reduced waste stream; Ability to increase production without requiring additional, and possibly constrained, energy supply; Avoidance of capital expenditures through greater utilization of existing equipment assets; Recognition as a "green company"; and Access to investor capital through demonstration of effective management practices.	
			"Luken (2007) compares regional levels of energy use intensities in 2004 and calculates that if all developing	Target setting agreements that "provide strong economic incentives as well as technical and

		countries met the developed country average manufacturing energy use intensity, energy consumption could potentially be reduced by 70%" (11).	financial support to participating industries" "have been used by a number of governments as a mechanism for promoting energy efficiency within the industrial sector." (p. 30) Key elements of a target setting program: • target-setting process; • identifying energy-saving technologies and measures, using energy-efficiency tools, guidebooks; • benchmarking current energy efficiency practices, • establishing an energy management plan (see Section 4.3 below); • conducting energy-efficiency audits; • developing an energy-savings action plan; • developing incentives and supporting policies; • measuring and monitoring progress toward targets, and • program evaluation.
		Potential industrial energy efficiency gains are larger in developing countries "where old, inefficient technologies have continued to be used to meet growing material demands" (3).	Energy Management Standards – provides guidance for industrial facilities to integrate energy efficiency into their management practices by requiring facilities to develop energy management plans.
		A focus on individual component energy efficiency means a potential failure to adopt processes, which would improve the whole system efficiency. System energy efficiency requires attention to the entire system.	System Optimization and Capacity Building – seeks to design an industrial system to achieve "a balance between cost and use that applies energy resources as efficiently as possible" (47). Generally, this kind of optimization is not taught in universities and requires additional special training to create a "cadre of highly skilled system optimization experts."
		"The presence of energy-efficient components, while important, provides no assurance that an industrial system will be energy-efficient. Misapplication of energy-efficient equipment (such as variable speed drives) in these systems is common." (5-6).	Documenting for Sustainability – "ISO 9000/14000 Series Standards would require continuously monitoring an organization's adherence to the new energy system-operating paradigm" (49). Also, a systems optimization

				library would better enable firms to comply with the energy management standards and energy efficiency projects.
Meyers, S. (1998). *Improving energy efficiency: strategies for supporting sustained market evolution in developing and transitioning countries.* Berkeley: Lawrence Berkeley Laboratory.	"This report represents a framework for considering market-oriented strategies for improving energy efficiency that recognize the conditions of developing… countries." Discusses policies to overcome barriers.		Macroeconomic conditions – Low level of competition among firms resulting from regulation of the domestic market and/or policies that constrain entry of imported products into the market High tariffs on imported goods Low level of capital market development High rate of inflation Uncertain status of firms (in transitioning economies) High level of income inequality Weaknesses in the legal framework	Improving information about energy efficiency opportunities Marketing and consumer education Information systems and databases Decisions support tools Best practices guidelines Common user specifications Demonstrations Product labelling and rating (comparison or endorsement) Energy audits
			Energy pricing prices - may not reflect cost of supply due to lack of marginal cost pricing or time-of-day pricing, or the presence of price subsidies prices do not incorporate externalities weak feedback between energy consumption and payment for energy	Financing of energy efficiency investments Leasing Performance contracting (transfers some tech and management risk away, minimizes up-front cash requirements) Vendor financing Special-purpose funds (across specific end-uses, where credit analysis can be reduced by having similar end-user credits, where capital demand is large enough to justify a fund, and to assist an existing association in marketing its finance program to its members) Utility financing programs
			International flows of capital, technology, and knowledge restrictions on capital flows (unreliable and restrictive policies, and fluctuating exchange rates) restrictions on technology flows (MNC practices and governmental policies, small market size/inability to gain local production technologies) barriers to knowledge and communication flows (lack of resources including publications and reliable internet access)	Minimum efficiency standards Equipment efficiency standards Building energy codes
			Institutional weaknesses - inadequate education and	Market aggregation and technology procurement

			research institutions government institutions lacking trained personnel financial institutions lacking experience with relevant investments and financing schemes electric utilities lack of incentives to improve end use efficiency, lack of skilled staff to design/manage programs	Bulk purchases
			Market behaviour and features – barriers on the demand side of the market (lack of information; irrational behaviour – insignificant energy costs, different priorities, no clear responsibility for managing energy costs, demand for rapid payback on investments/high discount rate; misplaced incentives; limited access to financing) Barriers on the supply side – (Limited availability of products or services, weakness of suppliers in market research, weakness of suppliers in product development, weak marketing capabilities of suppliers, low level of information exchange within an industry)	Voluntary commitment and recognition
			Features of energy-efficient products or services – performance uncertainties of new and unfamiliar technologies, worsened when coupled with high initial cost requirements high first cost transaction costs Inseparability of product features	Financial Incentives for energy efficiency investments most common consumer programs: consumer rebates or grants, low or zero-interest loans, tax credits, accelerated depreciation of energy-saving technologies, and no-cost direct installation manufacturer incentives have the benefit of less paperwork and lower admin costs, and possibly larger reduction in retail product price
Praetorius, B., & Bleyl, J. W. (2006). Improving the institutional structures for disseminating efficiency in emerging nations: a case study for	Discussion of common barriers to energy efficient investments and the best design of an energy agency.	Recommendations and lessons specific to South Africa, but discusses several other experiences with EAs.	Informational Barriers: "Information is expensive, or does not exist, or is not available to an extent that would permit an efficient investment decision. Understanding and valuating information presumes a certain level of skills. Asymmetric information causes distrust and conservative behaviour. These barriers are particularly relevant on the level of the individual households." (1521)	To overcome barriers: 1) diversify risk by bundling many small risks 2) tech or innovation diffusion can be promoted by disseminating information on pilot studies or projects and by large-scale programmes 3) successful and innovative energy efficiency policies are also connected to an appropriate and efficient institutional setting.
			Financial barriers: "Many consumers will not make	

energy agencies in South Africa. *Energy Policy*, *34*, 1420-1531.			investments in energy efficiency because they lack capital to buy new energy-efficient equipment or make the required retrofit in their installations” (1521)	
			Technological barriers and infrastructure: “Several opportunities to produce and to conserve energy depend on new technologies that may not be available in some countries or regions. Also, many new and efficient technologies incorporate electronic components which rely on good quality power to operate.” (1521-22)	
			Bounded rationality: “…linked to the first barrier above, i.e. information cost: Based on his/her experience, it may at least seem (or even be) rational to avoid further information cost and to take a “satisficing” rather than a theoretically optimal decision” (1522).	
			Discrepancies in discount rate: “Innovative energy efficiency investments or programmes often involve a number of actors with different perceptions of costs and benefits, risks and uncertainties. Utilities, large consumers and government can more easily afford investments with longer pay-back periods” (1522)	
			Diversity of investment criteria and limited resources: “Even when a certain investment in energy efficiency is cost effective, it may not be the first investment criterion.” Also, inconveniences may be related to new energy technologies, and the necessary investment may therefore be declined. (1522).	
Farell, D., & Remes, J. (2009). *Promoting energy efficiency in the developing world.* McKinsey & Company.		Developing countries	Information barriers	“Reduce energy subsidies, as they tend to lower energy productivity” (3).
			Capital constraints	Provide incentives to utilities to improve energy efficiency and to encourage their customers (including industries) to do the same.
			Insulation from true price of energy	Implement and enforce energy efficiency standards to boost production of more efficient appliances and equipment and to reduce their cost.
			Today’s tighter credit markets are making any	Encourage “public-private partnerships, such as

			investments more difficult, even less risky one such as those in energy efficiency	collaborations between governments, energy service companies, utilities, and mortgage companies, to finance higher energy efficiency in buildings" (5).
Taylor, R., Govindarajalu, C., Levin, J., Meyer, A. S., & Ward, W. A. (2008). *Financing Energy Efficiency: Lessons from Brazil, China, India and Beyond.* Washington DC: The World Bank Group.			Brazil, China and India faced the following key impediments to energy efficiency investment: "current high transaction costs; perceived high risks driving up the implicit discount rates associated with projects; and difficulties in structuring workable contracts for preparing, financing, and implementing energy efficiency investments" (50).	
			Common impediments: • lack of information • lack of trained personnel or technical or managerial expertise • below long-run marginal cost pricing and other price distortions (in some cases) • regulatory biases or absence • high transaction costs • high initial capital cost or lack of access to credit • high user discount rates • mismatch of the incidence of investment costs and energy savings • higher perceived risks of the more efficient technology	
			Also: missing or incomplete markets, in particular for financial risk Political and economic uncertainty Weak contracting institutions (legal systems) result in insecure contracts with low certainty of equitable enforcement	
Energy Sector Management Assistance Program. (2006). *Energy Efficiency*			Energy efficiency promotion activities for Industry: Regulation measures Tax incentives Energy efficiency funds and low interest loans Performance codes, standards, incentives and regulations	Findings of the 3 country study: "Overall, the conclusions show that success requires careful diagnostic work at the beginning of the project, flexibility in design and arrangements to cover high labor intensities during implementation

Investment Forum: Scaling up Financing in the Developing World. Washington DC: The World Bank Group.			Mandatory/compulsory energy efficiency targets Technical assistance and small business programs Energy audits for factories Product labelling, rating, certification and retro-commissioning Energy conservation management Recognition programs, technology adaptation and upgrades; and bulk procurements	and program development. The World Bank found that the development of financially viable energy savings projects remains blocked by the underdeveloped state of project delivery mechanisms. Developing appropriate delivery mechanisms is an institutional issue which must be addressed as delivery mechanisms serve market development, project identification and financing functions. Well-running project delivery mechanisms must match local institutional environments. The main project delivery options include energy efficiency lending programs through local banks, partial risk loan guarantee programs, direct financial investment, revolving loan programs, ESCOs and utility DSM programs” (32).

Printed in Austria
V.11-87135—December 2011—300

UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION
Vienna International Centre, P.O. Box 300, 1400 Vienna, Austria
Telephone: (+43-1) 26026-0, Fax: (+43-1) 26926-69
E-mail: unido@unido.org, Internet: www.unido.org