The role of efficiency in energy policy

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Abstract: Energy availability and use are issues of considerable concern in both developed and developing countries due to the rapid growth of energy demand relative to the available supplies, the uncertainty about the future supplies of energy, the high cost of energy to consumers, and global warming that is driven, largely, by greenhouse gas emissions that originate from activities related to the production and use of energy. Many nations have responded to these concerns by developing energy policies that are aimed at increasing the supplies of energy, developing alternative energy-conserving technologies, and improving the efficiency with which energy is used. This paper examines energy efficiency, its role in energy policy, and some specific measures that various countries are implementing to improve energy efficiency. Some of the criticisms that have been levelled against energy efficiency are evaluated and addressed and suggestions made to more effectively harness the potential of energy efficiency.

Keywords: energy efficiency; energy intensity; energy policy; sustainability; climate change; greenhouse gas emissions.

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1 Introduction

The rapid growth in energy use has been a central feature in many countries over the last three decades as they strive to expand the production of goods and services, and improve the standards of living. Other drivers of this growth in energy use have been the growth in population, increase in incomes, the increasing use of energy-using consumer goods, and shifts in production patterns towards more energy-intensive techniques. Based on past trends, this growth in energy use can be expected to continue into the foreseeable future. The growth in energy use has, however, resulted in several concerns that include doubts about the sustainability of current levels of energy use, the harmful environmental impacts of the increased production and use of energy, the depletion of scarce energy resources, and high energy prices. The high and rising energy prices have in turn resulted in high energy costs for households, reduced profit margins for firms, and diminished competitiveness for countries that rely on energy-intensive industries. In countries such as the USA that consume large amounts of oil, energy has come to be regarded as critical for national security. In developing countries, harnessing energy resources continues to be a significant challenge that can, at least partly, explain their poor economic performance. According to UNEP (2008) a lack of access to reliable and affordable energy is holding back economic and social development in many parts of the developing world today. The balance of payments of these countries significantly depends on energy imports and is particularly vulnerable to shocks in the international economy.

The approaches that various countries have used to address the rapid growth in energy demand include expanding the energy supplies through measures such as drilling new oil wells, developing offshore oil resources, undertaking investments in renewable energy such as solar and wind power, and developing technologies that are more energy efficient. The development of renewable energy resources is a policy that is being increasingly adopted in several countries due to greater awareness that existing supplies of energy are finite, and also as a means of decarbonisation that is intended to mitigate climate change. These measures are however not sufficient to align the growth in energy demand with the supplies of energy. It has prompted many economists and policy makers to advocate demand management approaches that use market-based instruments. The proponents of this approach argue that the rapid growth in energy demand is primarily due to low energy prices that provide energy consumers with a strong incentive to consume high amounts of energy. They recommend measures such as removal of subsidies on energy and the introduction of energy taxes to stem the growth in energy demand. The effect of these price-based measures are however likely to be minimal because energy, in general, has a low price elasticity of demand. Furthermore, energy is also a key factor in both economic production and in the provision of services that are needed to improve living standards.

Given the limitations of several measures designed to ensure the availability of affordable and reliable supplies of energy, the improvement of energy efficiency is increasingly regarded as a promising and effective low cost approach to reduce both energy demand and greenhouse gas (GHG) emissions. Sebitosi (2008), Trianni et al. (2014) and Gillingham et al. (2006) favour this position and are categorical that policies that encourage consumers and manufacturers to use less energy can assist in managing energy needs at little or no cost. Allan et al. (2007), Shellenberger and Nordhaus (2014), Granade et al. (2009), Tanaka (2011), Azevedo (2014), Trianni et al. (2014) and Worrell et al. (2003) maintain that improving efficiency boosts productivity and results in both higher output and higher consumption. However, although energy efficiency has been identified as vital in stemming the growth in energy demand, several scholars question its effectiveness in achieving this objective. Jenkins et al. (2011), Sorrell (2009), Owen (2010), Michaels (2012), and Herring (2006), for example, argue that since energy efficiency reduces the effective price of energy, it has the effect of increasing the demand for energy. This is a plausible argument from a theoretical standpoint and merits further investigation. Empirical evidence however suggests that the magnitude of the rebound effects is small (Gillingham et al., 2013). Loughran and Kulick (2004) have also questioned energy efficiency demand side management programs and contend that utilities have been overstating electricity savings and understating the costs associated with these programs.

The purpose of this paper is to clarify the concept of energy efficiency and to examine how energy efficiency policies can be used to restrain the growth in energy demand. Past performance of many specific energy efficiency policies and programs are discussed and the lessons from these experiences set out. In the next section, energy efficiency is defined and a distinction made between energy efficiency and energy intensity. Section 3 presents a simple model to illustrate the effects of energy efficiency on an economy's consumption and total energy use. In Section 4 data on general trends in energy production, consumption and prices are presented and discussed. Section 5 discusses some specific measures that can be used to promote energy efficiency. Section 6 discusses energy efficiency indicators and their application in monitoring changes in energy efficiency. Selected empirical examples from Canada are presented to illustrate the improvements in energy efficiency that have been taking place over time. In Section 7 the common criticisms that have been levelled against energy efficiency are presented and evaluated. In Section 8 some barriers to investments in energy efficiency measures are identified and suggestions made for addressing these barriers. The paper concludes in Section 9 with a summary of the main points and a discussion of their implications for public policy.

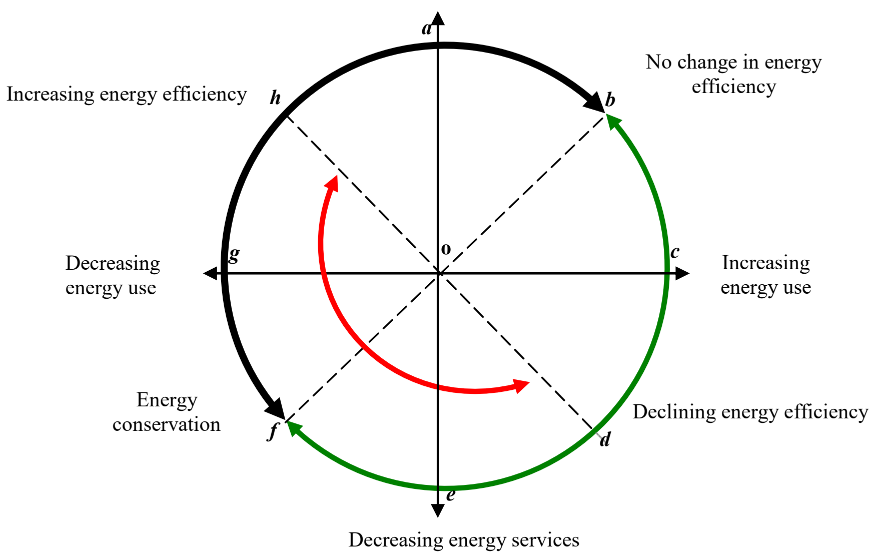
2 Definitions of energy efficiency and its importance

Energy efficiency has been defined in various ways by different organisations and individuals depending on the purpose. According to the World Energy Council (2008), "energy efficiency improvements refer to a reduction in the energy used for a given service (heating, lighting, etc.)or level of activity (p.9)". The International Energy Agency (2008) defines energy efficiency as "greater energy services-such as production, transport and heat – per unit of energy (i.e., coal, gas, electricity) (p.19)". According to the Office of Energy Efficiency of Natural Resources Canada, "energy efficiency refers to how effectively energy is being used, that is, using less energy to provide the same levels of energy service" [OEE, (2011), p.9]. To a large extent, these reductions in energy consumption are brought about by improvements in technology or processes. Some examples of energy efficiency innovations are newer refrigerators that use less energy than older models; motor vehicles that travel greater distances for given amounts of fuel; heating and cooling systems that consume less energy; replacement of incandescent lights with fluorescent lights; and, industrial processes that use less energy to produce given output levels. But reductions in energy consumption can also result from non-technological factors such as better organisation and management (World Energy Council, 2008).

A concept that is closely related to energy efficiency is energy intensity. It refers to the amount of energy used per unit of gross domestic product (GDP). Two types of energy intensity measures can be identified. The first is primary energy intensity which is the quotient of primary energy consumption compared to GDP. The second is final energy intensity which is the quotient of final energy consumption (industry, transport, household, tertiary sector, agriculture) compared to the GDP. According to this definition, using less energy to produce a product reduces the energy intensity.

The changes in the energy intensities that have been recorded in the various end-use sectors in different countries can be attributed to diverse factors such as the level of economic activity, the weather, the economic structure, and the extent of energy efficiency. Thus, the analysis of trends in energy intensities needs to be accompanied by a decomposition procedure that allows for the contributions of the various factors to be separated out. It also implies that although energy intensity and energy efficiency are often used interchangeably in energy policy discourse, this practice is erroneous because the two concepts, although closely related, do not mean the same thing.

Figure 1 Illustration of energy efficiency (see online version for colours)



Source: Energy Efficiency and Conservation Authority (2009)

Figure 1 shows that changes in energy use may or may not be associated with an increase in energy efficiency depending on whether the change in energy use is accompanied by an increase or a decrease in the level of energy services.

There is no change in energy efficiency when an increase in energy use is accompanied by a proportionate increase in energy services (*ob*) or when a decrease in energy use is accompanied by a proportionate decrease in energy services (*of*). There is an improvement in energy efficiency when an increase in energy use is accompanied by a more than proportionate increase in energy services (*oab*), and when a decrease in energy use is accompanied by either an increase in energy services (*oag*) or a less than proportionate decrease in energy services (*ogf*). A decrease in energy efficiency will occur when an increase in energy use is accompanied by a less than proportionate increase in energy services (*obc*) or a decrease in energy services (*oce*). A decrease in energy efficiency also results when a decrease in energy use leads to a more than proportionate decrease in energy services (*oef*). It follows from Figure 1 that energy conservation (reduction in energy use) does not necessarily imply improvements in energy efficiency. It is important to note that the ratio of energy use to GDP is an aggregate of sectoral energy intensity indicators. For this reason it is linked to the energy intensities of the manufacturing, transportation, commercial/services, and residential sectors.

3 Model

To clarify the effects of energy efficiency on energy use and overall consumption in an economy, I present a simple model in which energy is one of the inputs in production. The model is adapted from Allan et al. (2011). If the economy under consideration produces output Q of a single product using a fixed quantity of natural resources N and homogeneous energy input E, the relationship between Q, N and E is determined by a production function that can be specified as follows:

$$Q = Q(N, E) \tag{1}$$

For the production function specified in equation (1) to be well-behaved we assume that

$$Q(N, 0) = Q(0, E) = 0; \quad \frac{\partial Q}{\partial E} > 0; \quad \text{and} \quad \frac{\partial^2 Q}{\partial E^2} < 0$$

This specification of the production function implies that no output will be obtained when no energy inputs are used and that with fixed amounts of the other inputs an increase in energy use will result in the output increasing at a decreasing rate. If the output is taken to be the numeraire good so that its price is 1 and the price of the energy input is P, the profit obtained from energy use can be expressed as

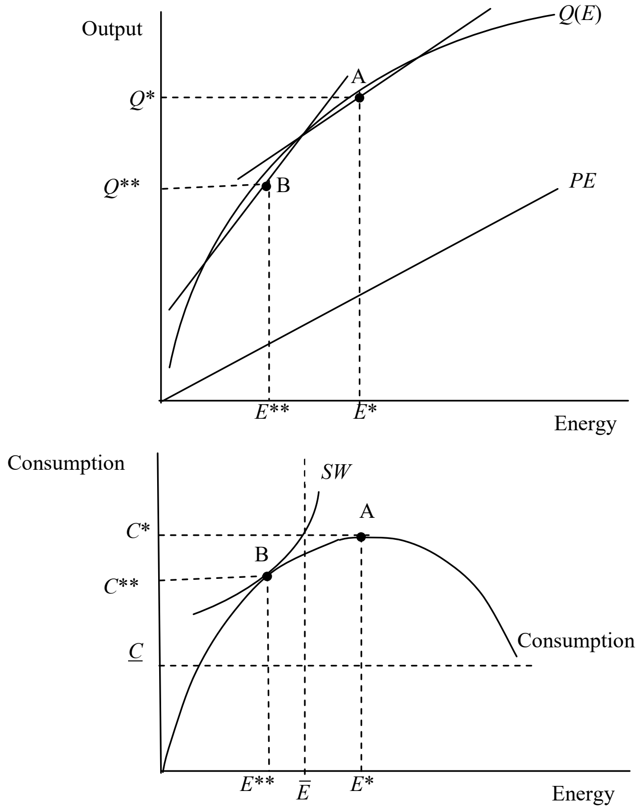
$$\pi = Q(E) - PE \tag{2}$$

The first order condition for profit maximisation is:

$$\frac{\partial \pi}{\partial E} = Q_E(E) - P = 0 \Rightarrow Q_E(E) = P \tag{3}$$

Equation (3) implies that profit is maximised when the marginal value product of energy is equal to the energy price. This occurs at point A in the upper panel of Figure 2 where the slope of the cost of energy curve is equal to that of the production function which is represented by $Q(E)$. This point coincides with point A in the lower panel of Figure 2. At point A, the output is Q^*, the consumption is C^*, and the energy use is E^*. The assumption here is that maximisation of consumption occurs where the profits are maximised.

Figure 2 Production function, optimal allocation and effect of energy efficiency

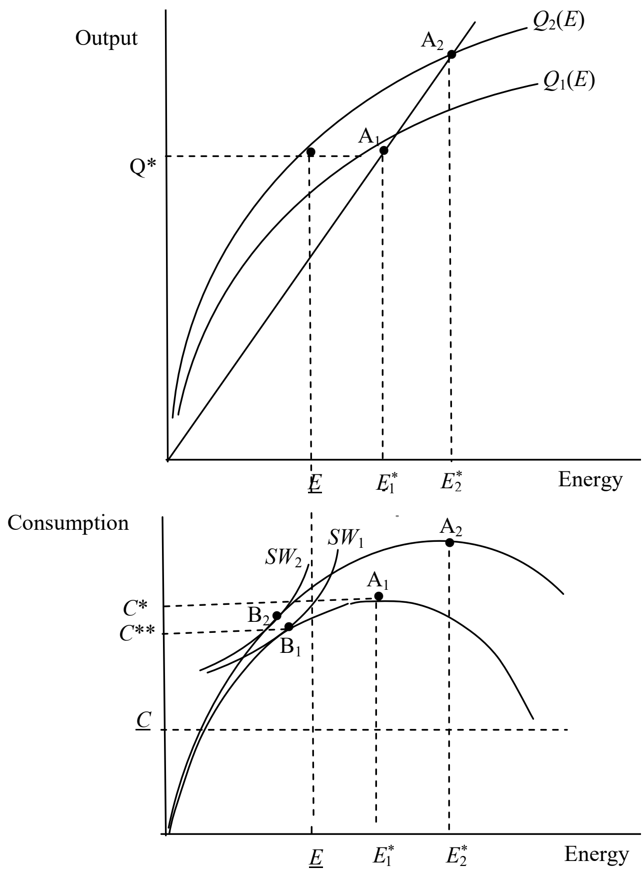


A key consideration in the formulation of energy policy is how to ensure that energy is used in a sustainable manner. A sustainability constraint can be constructed by specifying a minimum level of consumption $\underline{C}$ and a maximum level of energy use in production $\bar{E}$.. In the energy input-commodity output space defined by $C > \underline{C}$ and $0 < E < \underline{E}$, there is a family of convex social welfare (SW) curves where each curve represents combinations of consumption and energy use that produce the same level of SW. SW is maximised, where the highest SW curve in the lower panel of Figure 2 is just tangent to the consumption curve. This is shown by point B in both the upper and lower panels of Figure 2. At point B, where the sustainability constraint is satisfied, the output is Q^{**}, the consumption is C^{**}, and the energy use is E^{**} where $Q^{**} < Q^*$, $C^{**} < C^*$, and $E^{**} < E^*$.

Figure 2 implies that with fixed resources and technology, achieving technical and allocative efficiency requires sacrificing some consumption. This is the case in part because sustainability involves giving positive weight to the well-being of future generations. In a decentralised competitive market system, this can be achieved through by instituting a tax on energy so as to make the price of energy equal to the slope of the production function at B.

Energy efficiency has the effect of moving the production function upwards and to the left. According to Gillingham et al. (2008), technological change is one of the drivers of energy efficiency that enables an economy to produce more output from a given input level through invention, innovation, and diffusion. In the upper panel of Figure 3, an improvement in energy efficiency is depicted by the shift in the production function from $Q_1(E)$ to $Q_2(E)$. When an improvement in energy efficiency occurs, it is possible to achieve sustainability with a fall in energy use and a simultaneous increase in consumption. This is shown in Figure 3 by the movement from point B_1 to B_2.

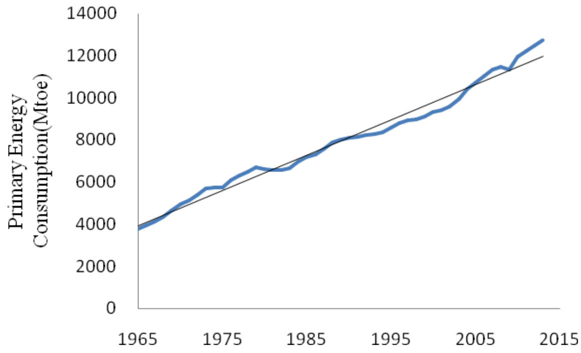
Figure 3 The effects of energy efficiency on output, consumption and energy use



4 Trends in energy production and consumption, and emissions

Over the past several decades the total world primary energy consumption and also the consumption of specific fuels has been rising steadily due to, among others, population growth, economic expansion, and policies that encourage higher levels of energy use. The growth in energy consumption that has been occurring over time at the world scale is depicted in Figure 4.

Figure 4 World primary energy consumption (MTOE) (see online version for colours)



Source: *BP World Energy Statistics 2014* (http://www.bp.com)

Although the overall trend in energy consumption has been upward, there have been brief periods characterised by weak or even declining energy demand. Three such periods were during the oil crises of the 1970s, the economic recession in the early 1980s, and the financial crisis of 2007/2008.

In terms of the types of energy, oil, coal, and natural gas have been and continue to be the dominant fuels. This is due to their relative abundance, and technological and structural constraints. Table 1 summarises the historical pattern on the use of specific fuels and projections of how the use of these fuels is likely to evolve in the future.

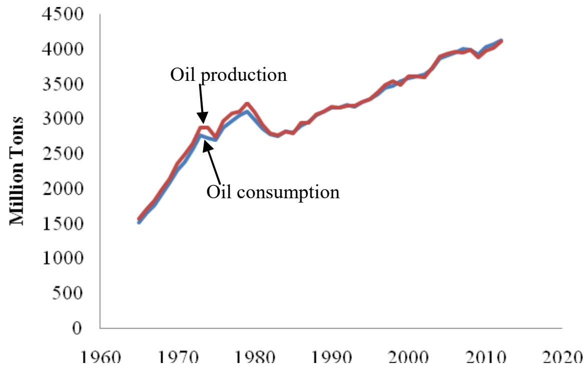
Table 1 World energy demand by fuel in the reference scenario (Mtoe)

	1980	*2000*	*2007*	*2015*	*2030*	*2007–2030*
Coal	1,792	2,292	3,184	3,828	4,887	1.9%
Oil	3,107	3,655	4,093	4,234	5,009	0.9%
Gas	1,234	2,085	2,512	2,801	3,561	1.5%
Nuclear	186	676	709	810	956	1.3%
Hydro	148	225	265	317	402	1.8%
Biomass	749	1,031	1,176	1,338	1,604	1.4%
Other renewable	12	55	74	160	370	7.3%
Total	**7,228**	**10,018**	**12,013**	**13,488**	**16,790**	**1.5%**

Source: International Energy Agency (2009) world energy outlook

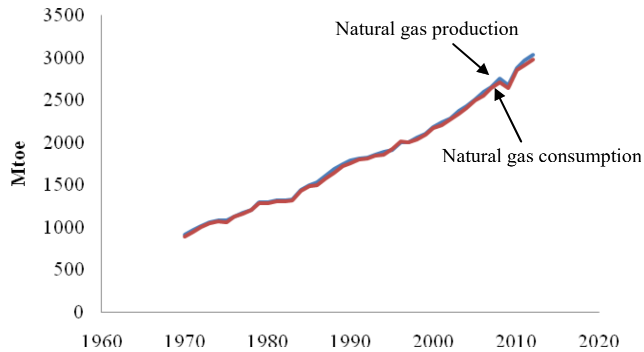
The data in Table 1 confirms the dominant role of oil, coal and natural gas in the energy mix. These are the fuels that are mostly used in the transportation, industrial and residential sectors. Compared to coal and natural gas, however, the annual growth rate in oil consumption is expected to below (about 0.9% per year). This is partly due to the high prices of oil, and the efforts that are currently being implemented to not only improve the efficiency of oil consumption, but also to substitute away from oil. Table 1 also shows that although renewable energy resources currently constitute a small share of the total energy demand, the projected rate of growth of renewables is higher than that of the other fuels as measures are increasingly taken to replace fossil fuels with renewables. The high initial cost of renewable energy technologies has however to some extent slowed the rate of adoption of these technologies. As the costs of these technologies fall over time, higher rates of adoption can be expected.

Figure 5 World oil production and consumption (see online version for colours)



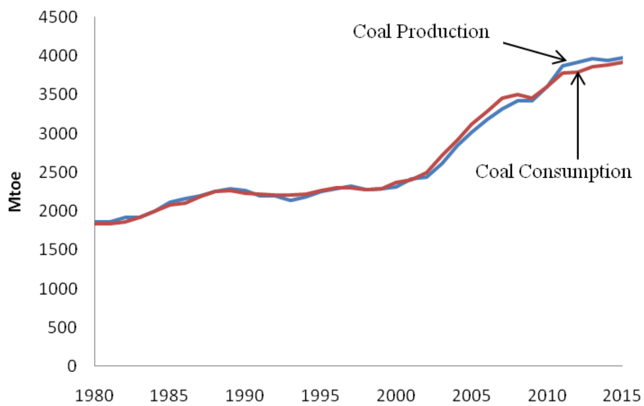
Source: *BP World Energy Statistics 2014* (http://www.bp.com)

Figure 6 World natural gas production and consumption (see online version for colours)



Source: *BP World Energy Statistics 2014* (http://www.bp.com)

Figure 7 Coal production and consumption (see online version for colours)



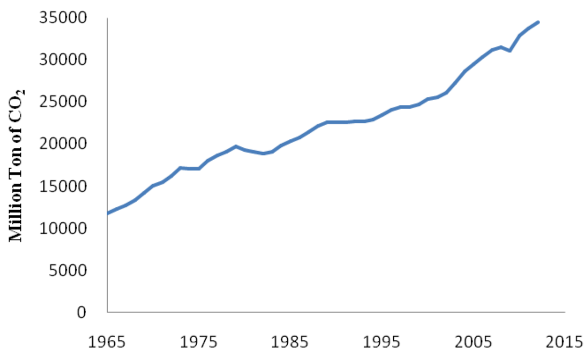
Source: *BP World Energy Statistics 2014* (http://www.bp.com)

At the global level, the consumption of oil, coal and natural gas has over time closely followed the production of these fuels. The trends in the production and consumption of oil, coal and natural gas are shown in Figures 5, 6, and 7 respectively.

A serious shortcoming of analysing energy production and consumption at the global level is that is masks the energy situations that actually exist in specific countries. For example, in India, China, Japan, and several countries in the European Union, the consumption of oil, coal, and natural gas is much greater than the domestic production thus necessitating the reliance of these countries on energy imports. These energy imports are projected to rise due to the dynamic economic growth and modernisation that is occurring in these countries.

Addressing energy issues is urgent because it is intricately linked to the problem of climate change that has been attributed to rising GHG emissions. In general it is countries that consume large amounts of fossil fuels, particularly oil and coal that are the major emitters of GHGs. It is the actions of these countries that can explain the global trend in carbon dioxide emissions that is depicted in Figure 8. Energy efficiency and the use of clean fuels can slow the rate of GHG emissions into the atmosphere and thus curtail significant increases in global temperatures.

Figure 8 World CO_2 emissions (see online version for colours)

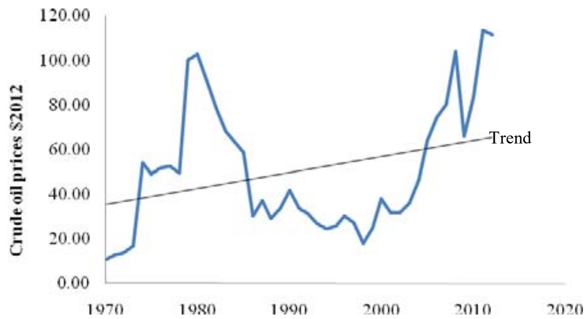


Source: *BP World Energy Statistics 2014* (http://www.bp.com)

A major concern that has slowed global efforts to curb GHG emissions is that measures directed towards this goal can have adverse economic impacts particularly in countries that are large emitters of GHGs. This view is premised on the fact that GHG emissions are largely a by-product of fossil fuels' consumption in the process of economic production. Given that energy efficiency entails a reduction in the amount of energy used to produce given amounts of economic output, it holds considerable promise as a policy instrument that can be deployed to mitigate the threat of climate change. Success in this endeavour however requires global cooperation within a framework that allows countries sufficient flexibility in realising their GHG emission reductions targets.

Figure 9 shows the trajectory of crude oil prices from 1970 to 2012. Although the crude oil prices exhibit considerable fluctuations, the overall trend has been upward. These prices rose significantly in the 1970s during the oil crises and were partly the factor that motivated several countries to craft and implement energy efficiency measures. More recently, however, the price of crude oil has declined significantly as a result of a temporary glut in the world oil markets, low demand due to weak economic activity, increased efficiency, a growing switch from oil to other fuels, and increased oil production and reduction in crude oil imports by the USA. This does not invalidate the need for more efficient energy use given the multiple benefits of energy efficiency as detailed by Ryan and Campbell (2012).

Figure 9 Crude oil prices 1970–2012 in $2012 (see online version for colours)



Source: *BP World Energy Statistics 2014* (http://www.bp.com)

5 Energy efficiency measures

To address the challenges presented by the rapid growth in the demand for energy and reduce the emissions of GHGs and other pollutants that cause environmental damage, a variety of measures and policies have been crafted and are being implemented by various countries. This is a critical step in realising the multiple benefits of energy efficiency whose existence has been documented in several studies. The International Energy Agency strongly supports the implementation of these measures and regards increasing energy efficiency as the quickest and least costly way of addressing energy security and environmental and economic challenges (IEA, 2013; Jollands et al., 2010). Some innovative energy efficiency measures that have been implemented successfully by various countries are discussed below.

1 *Efficient lighting*: in several countries a lot of effort has been expended to develop lighting systems that not only use less energy, but also waste less energy and have longer life cycles. For example, in Canada and the USA, regulations exist that mandate the transition from incandescent light bulbs to compact fluorescent lamps (CFLs). This has been promoted through information programs that increase awareness among consumers about the economic and environmental benefits of efficient lighting. These programs are important because CFLs generally cost more than incandescent light bulbs. Their widespread adoption can be attributed to information provided to consumers demonstrating that CFLs not only have longer lives, but also yield cost-savings that more than cover their costs over their life spans. According to the EPA (2011), CFLs use one fifth to one third of the electric power, and last ten to 25 times longer than incandescent lamps giving the same amount of visible light. A CFL, however, costs more than an incandescent lamp but can save over five times its purchase price in electricity cost over its lifetime.

2 *Energy-efficient buildings:* buildings account for approximately 40% of global energy usage (Yoo et al., 2013; UNEP, 2007). According to Di Placido et al. (2014), "the building sector is one of the most cost effective areas to reduce energy use and GHG emissions" (p.40). A critical determinant of the energy use in buildings is the building code. Several countries are in the process of strengthening their building codes in order to improve the energy performance of buildings and reduce GHG emissions. For example, the building code that Ontario adopted in 2012 has an environmental focus and contains several measures that are aimed at conserving energy and reducing GHG emissions. Some of the methods for improving building energy efficiency that are contained in the 2012 Ontario Building Code are greater insulation, more efficient windows, and more efficient natural gas and propane furnaces. The 2012 Ontario Building Code requires all new houses constructed in 2017 to be 15% more energy efficient that those built in 2012. It also requires large buildings such as tall residential and office buildings to be 13% more energy efficient than those built in 2012 (Ontario Ministry of Municipal Affairs and Housing, 2012).

Although implementing the more stringent energy efficiency standards specified in the 2012 Ontario Building Code entails additional costs, the expected payback period of the measures is short – about five years. The measures are also attractive because the expected savings in energy costs are substantial. The other provinces of Canada have developed similar measures and are implementing them as part of their climate change strategy. It is however important to recognise that the short-term impact of more stringent building codes on the energy performance of buildings is likely to be minimal because the buildings that will exist in the next 50 or so years have already been built and will not be affected by the changes to the building code. Thus, other approaches will be needed to achieve substantial reductions in GHG emissions and savings in energy costs. Some viable options for achieving this include implementing a broad buildings retrofit program and requiring energy upgrades when the ownership of buildings changes.

3 *Energy audits*: how energy is used in residential, commercial, institutional and industrial buildings have a significant effect on both the costs of operating those buildings and the GHG emissions from those buildings. Energy audits are important because they help in understanding how energy is used in buildings and can therefore contribute immensely towards improving the energy performance (Schleich, 2004). Energy audits entail, among others, comparing the energy performance of buildings against appropriate benchmarks that are established by taking into account the characteristics of buildings and the current local site conditions, identifying the specific causes of any deviations from the benchmarks, and determining cost effective ways to improve the efficiency of buildings. By helping to reduce energy use, energy audits can be instrumental in providing significant economic and environmental benefits (Schleich, 2004). The importance of energy audits is even greater today given the high and rapidly increasing energy costs to households and businesses. In cases where the costs of energy audits are prohibitive, programs that subsidise the costs of energy audits can significantly facilitate the uptake of energy efficiency measures identified through energy audits. This is the case, for example, in Canada where the eco-energy program includes initiatives that provide subsidies for home and industrial energy audits.

4 *Energy consumption labelling for equipment and appliances*: the energy efficiency of equipment and appliances such as televisions, computers, refrigerators, cookers, freezers, washing machines and dryers is a key factor affecting energy use. Over time, the energy efficiency of equipment and appliances has been increasing as a response to increasing energy prices, the concern about the emissions resulting from the use of these equipment and appliances, and the promulgation of more stringent regulations mandating higher levels of energy efficiency for the equipment and appliances being manufactured and availed in the market. In many countries, labelling programs have been developed to provide consumers with information about the energy consumption of the various models of equipment and appliances and the potential energy and cost savings that can be realised by replacing the inefficient models with the more efficient ones.

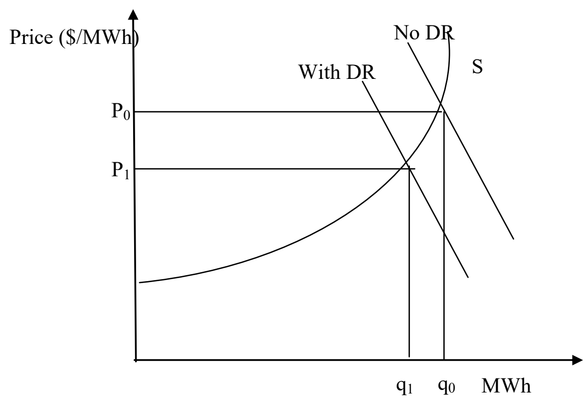
An example of a labelling program that has been effective in promoting energy efficiency of homes, equipment and appliances is the ENERGY STAR. It was established to reduce GHG emissions and other pollutants caused by inefficient use of energy and to make it easier for consumers to identify and purchase energy efficient products. Although some products with the ENERGY STAR label cost more than the conventional counterparts that are less energy-efficient, the purchasers of the energy efficient products are in many cases able to recover their investments in increased energy efficiency through utility bill savings within a reasonable time. The US Environmental Protection Agency (EPA) estimates that in 2013 alone, investments in energy-efficient technologies and practices through the ENERGY STAR program reduced utility bills by $30 billion, prevented more than 277 million metric tons of GHG emissions, and provided over $10 billion in benefits to society by reducing damages from climate change (EPA, 2014).

5 *Demand response:* according to Albadi and El-Saadany (2008), Aalami et al. (2010), and Spees and Lave (2007), demand response programs are intended to induce changes in electricity use by end-use customers from their normal consumption patterns in response to changes in the price of electricity over time or to give incentive payments that are designed to induce lower electricity use at times of high market prices or when grid reliability is jeopardised. Price-based demand response programs e.g., real time pricing, critical peak pricing, and time of use tariffs give customers varying rates that reflect the value and cost of electricity at different time periods with the result that customers tend to use less electricity when the electricity prices are high (Albadi and El-Saadany, 2008; Aalami et al., 2010; Spees and Lave, 2007). They differ from conventional electricity pricing schemes that are based on flat, average cost retail rates that do not reflect the actual cost to supply power. The latter leads to inefficient investment in new generation, transmission, and distribution infrastructure and higher electricity bills for customers. The most important advantage of demand response is improved efficiency of electricity production due to the alignment between the customers' electricity prices and the value they place on electricity. Other benefits of demand response programs include bill savings and incentive payments earned by customers who adjust their electricity demand in response to time varying electricity rates or incentive-based programs; the lower wholesale electricity market prices that result because demand response programs avert the need to use the most costly-to-run power plants during periods of high demand; lower aggregate system capacity requirements that in turn allow

load-serving entities to purchase or build less new capacity; and, improved reliability of the electricity supply system because demand response lowers the likelihood and consequences of forced outages that impose financial costs and inconvenience on customers. Demand response programs can also provide firms with incentives to invest in energy-efficient technologies and processes, generate their own power, or shift production to off peak periods. Demand response programs also yield significant environmental benefits that include better land utilisation as a result of avoided or deferred new electricity infrastructure; air and water quality improvements as a result of efficient use of resources; and reduction in the depletion of natural resources (Albadi and El-Saadany, 2008; USDE, 2006).

The effect of demand response on the price and use of electricity is shown in Figure 10. The figure shows that as the maximum generation capacity is approached, the electricity costs increase exponentially. An increase in the demand for electricity will therefore result in a big increase in electricity price and only minimally increase the amount of electricity consumed. In such periods, a reduction in electricity demand will cause a big decrease in the price of electricity and yield substantial cost saving to the consumers.

Figure 10 The effect of demand response on electricity market prices



6 Energy efficiency indicators: selected empirical estimates from Canada

Although several reasons have been advanced to support the implementation of energy efficiency measures, the effectiveness of these measures needs to be empirically demonstrated in terms of either reduced energy costs and/or reduced energy consumption. One approach for demonstrating the effectiveness of these measures is constructing energy efficiency indicators that can also be used to track the progress being made to reduce energy consumption. Such indicators can be constructed using data on energy consumption and activity levels. To be meaningful, the indicators need to be constructed for specific end uses, and be based on disaggregated data. In what follows I discuss selected energy efficiency indicators to illustrate the trajectory of energy consumption in the residential, commercial, institutional, industrial, and transportation sectors in Canada.

a *Residential sector*: some of the energy efficiency indicators that can be used to assess the energy efficiency performance in the residential sector include the energy consumption per household, the energy consumption per floor area, and the appliance energy use per household. In Canada these indicators show a downward trend thus implying that the energy efficiency of the residential sector has been improving over time. The trends in these indicators are shown in Figures 11, 12 and 13.

Between 1990 and 2012 the energy consumption per household in Canada decreased by 26% from 144 GJ to 107GJ; the energy intensity of the residential sector decreased by 35.4% from 1.18 GJ/m^2 to 0.76 GJ/m^2; and, the appliance energy use per household fell by 25% from 17.9 GJ to 13.5 GJ. Improvements in energy efficiency also occurred in specific end-uses such as space heating, space cooling, water heating, and lighting. The drivers of the trends in energy efficiency exhibited in the diagrams above include change in consumer behaviour in response to rising energy prices, technological improvements, and energy efficiency programs and policies that have been instituted in the residential sector.

b *Transportation sector*: energy use in the transportation sector can be broken down into that due to transportation of people (passenger transportation) and that due to the transportation of goods (freight transportation). The energy efficiency indicators that are commonly used to track the energy efficiency in the transportation sector are the energy consumption per passenger-kilometre and the energy consumption per tonne-kilometre. In Canada, the efficiency of energy use for passenger transportation has been steadily improving over time as evidenced by the trend shown in Figure 14. Between 1990 and 2012 the energy intensity in passenger transportation in Canada decreased by 23% from 2.29 MJ/pkm to 1.77 MJ/pkm. The trend in Figure 14 is partly due to the fact that the share of more efficient vehicles in the total vehicle stock has been rising due to regulations that require greater fuel economy in the vehicles being sold in Canada.

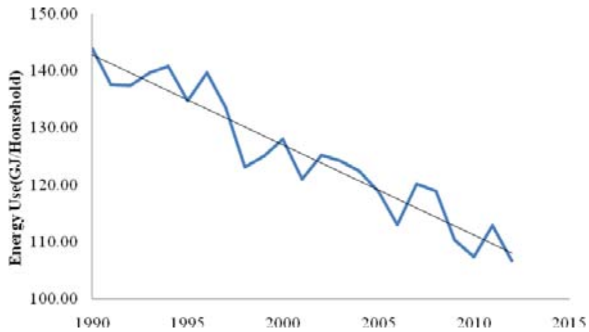
For freight transportation in Canada, the change in energy use per tonne-kilometre from 1990 to 2012 is shown in Figure 15. Fitting a trend line to the data from 1990 to 2012 yields an upward trajectory. However, if a trend line is fitted to the data from 1990 to 2007, a downward trajectory results. On the basis of these two properties of the freight transportation energy use data, the argument can be made that overall, freight transportation energy efficiency has been improving. The increase in energy intensity for freight transportation after 2007 was mainly due to the economic recession that significantly reduced the quantity of goods transported.

c *Commercial and institutional sector*: the commercial and institutional sector consists of establishments such as office buildings, schools, hospitals, hotels, and wholesale and retail stores. For this sector, the energy efficiency indicator that is commonly used to evaluate their energy performance is the energy use per floor area. In Canada, the energy use per floor area in the commercial and institutional sector increased between 1990 and 2000 except for a brief period between 1997 and 1998 when it decreased. From 2003 to 2012 the energy intensity of the sector declined by 19% from 1.8 GJ/m^2 to 1.43 GJ/m^2. These patterns are depicted in Figure 16. The overall trend for the period between 1990 and 2012 is however one of declining energy intensity in the sector thus implying an improvement in energy efficiency.

The trend in Figure 16 can be attributed to the adoption of energy efficiency measures that are aimed at reducing the energy consumption, saving on the energy costs, and increasing the profitability of the operations that are carried out in these establishments.

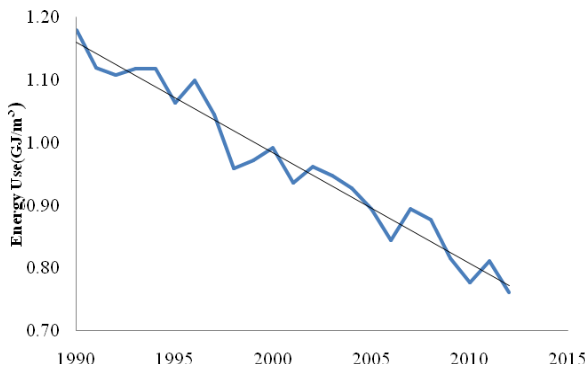
d *Industrial Sector:* Canada's industrial sector is one of the energy end-use sectors with the largest consumption of energy and has for this reason been the focus of concerted efforts to improve its energy efficiency. The indicator commonly used to evaluate progress in energy efficiency in the industrial sector is the energy use per dollar of real GDP. Figure 17 shows the trend in the energy intensity of the industrial sector in Canada between 1990 and 2012. Over this period the energy intensity declined by about 12.9% from 9.5 MJ/$2007 GDP to 8.3 MJ/$2007 GDP. The greatest decline in energy intensity in the sector however occurred between 1995 and 2001 when it fell by 19.2% from 9.9 MJ/$2007 GDP to 8.0 MJ/$2007 GDP.

Figure 11 Energy use for residential sector in Canada in GJ/household (see online version for colours)



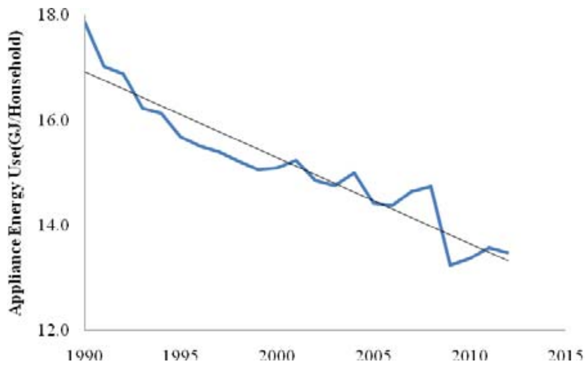
Source: OEE (2014)

Figure 12 Energy use for residential sector in Canada in GJ/m^2 (see online version for colours)



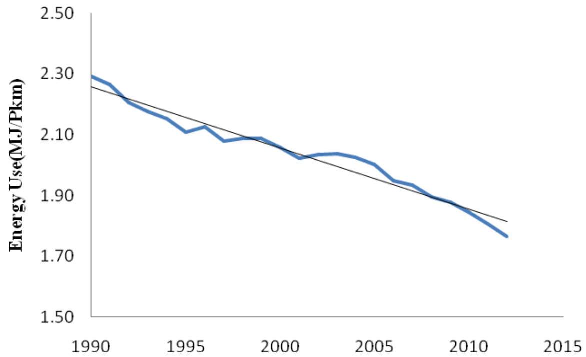
Source: OEE (2014)

Figure 13 Appliance energy use for residential sector in Canada in GJ/household (see online version for colours)



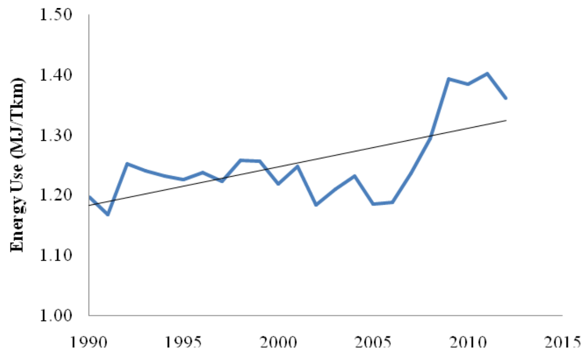
Source: OEE (2014)

Figure 14 Energy use in passenger transportation in Canada in MJ/pkm (see online version for colours)



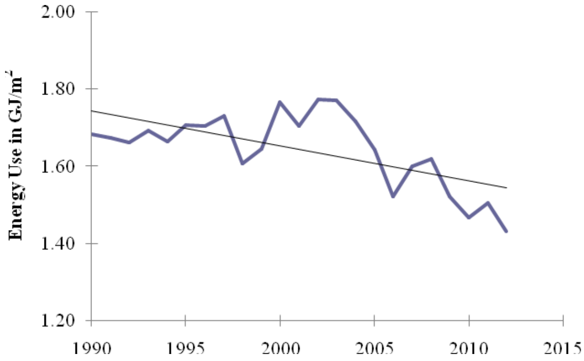
Source: OEE (2014)

Figure 15 Energy use in freight transportation in Canada in MJ/Tkm (see online version for colours)



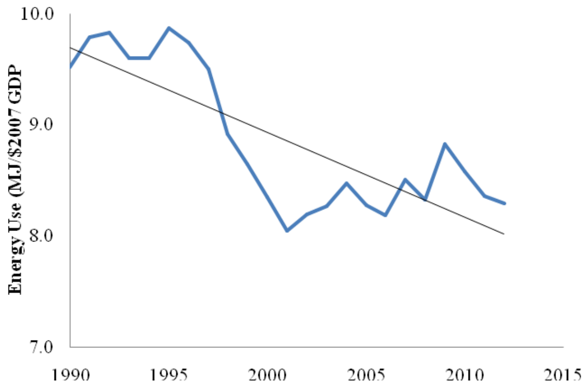
Source: OEE (2014)

Figure 16 Energy use in commercial and institutional sector in GJ/m² (see online version for colours)



Source: OEE (2014)

Figure 17 Energy use in industrial sector in Canada in MJ/$ 2007 GDP (see online version for colours)



Source: OEE (2014)

7 Criticisms of energy efficiency measures

Several scholars have levelled various criticisms against the use of energy efficiency policies to address the challenges of rising energy demand and climate change. The thrust of these criticisms has been that energy efficiency policies are costly to implement and have not achieved the objectives for which they were intended. In what follows I identify and evaluate three specific criticisms of energy efficiency.

1 *The rebound effect will erase most of the energy savings:* the rebound effect refers to the increase in the demand for energy services as a result of technological improvements in energy efficiency (Sorrell, 2009; Saunders, 1992; Shellenberger and Nordhaus, 2014). Its existence is premised on neoclassical microeconomic theory which maintains that improvements in energy efficiency reduce the effective cost of energy services which in turn induces behavioural changes among users of energy in a manner that increases energy consumption anderodes the energy savings

(Geller and Attali, 2005; Greening et al., 2000; Allan et al., 2007; Sorrell, 2009; Saunders, 1992; Shellenberger and Nordhaus, 2014). Some examples that are commonly cited to support this argument are the tendency of the owners of more efficient vehicles to drive their vehicles more (Sorrell, 2009); the increased tendency of the owners of energy efficient homes to raise the thermostat levels in the winter months; and, the tendency of the buyers of more efficient appliances to operate them more frequently.

Although the core argument advanced in support of the rebound effect is plausible, it does not invalidate the critical role that energy efficiency can play in an economy with restricted energy supplies nor does it constitute incontrovertible evidence that energy efficiency is a failure. It merely indicates that some consumers respond to reduced energy costs by increasing their level of space heating or cooling instead of minimising their energy consumption and energy costs. In such cases, energy efficiency improvements still enhance general welfare by enabling a higher level of comfort, increased activity or lower energy cost (Geller and Attali, 2005). Furthermore, as Laitner (2000) and Gillingham et al. (2013) have pointed out, several studies report that the estimates of the rebound effect are small to moderate so that a substantial proportion of the energy savings from energy efficiency measures will still be realised.

2 *Energy savings in the economy have occurred independent of energy efficiency policies*: there is empirical evidence that autonomous energy efficiency improvements have been occurring over time resulting in a decline in the energy intensity. Some critics of energy efficiency argue that the energy savings from such ongoing technological advances would occur irrespective of whether energy efficiency policies were implemented or not. They therefore maintain that the energy savings from measures such as improvements in appliance efficiency standards are much less than claimed.

Although there is some merit in the claim that autonomous energy efficiency improvements have resulted in energy savings over time, the energy savings that have been realised over time cannot be entirely attributed to autonomous improvements in energy efficiency. Several studies actually indicate that the rate of energy intensity reduction accelerated rapidly in the past 40 or so years due to more stringent efficiency standards, rising energy prices, and various incentive schemes. Energy efficiency policy measures have contributed substantially to these energy savings and it is clearly erroneous to discount the various energy efficiency policy measures and minimise their role in restraining the growth in the demand for energy and reducing GHG emissions (Nadel, 2002).

3 *Energy use has been increasing even with energy efficiency policies*: in several countries, the overall energy use has been rising over time due to factors such as population growth, economic expansion, and increase in income. This increase in energy use has been occurring even as these countries increasingly adopt and implement energy efficiency measures such as vehicle efficiency, appliance efficiency, and home and building retrofit programs (Linares and Libandeira, 2010). Some critics of energy efficiency such as Rudin (2000) cite the increase in energy use at a time when more efforts are being directed towards improvements in energy efficiency as evidence that energy efficiency policies result in increased rather

decreased energy use. For this reason, the critics claim, energy efficiency is not an effective means for restraining the growth in energy demand or ensuring long-term environmental sustainability. The argument that is advanced to underpin this claim is that new energy-efficient technologies open up new applications that increase the economic output and/or standard of living in such a manner that sooner or later the direct energy savings are overtaken by the 'growth effects' (Geller and Attali, 2005).

The fact that energy use has been increasing at a time of expanded energy efficiency measures does not imply that the growth in energy use is caused by energy efficiency improvements. Although energy use has been increasing, it has been increasing more slowly than it would have increased without energy efficiency improvements. In China aggressive energy efficiency programs enabled the country to limit energy demand growth to less than half of GDP growth between 1970 and 2001 (Zhou, 2010). In Canada it is estimated that between 1990 and 2009 the energy use increased by 23% from 6,936.1 PJ to 8,541.6 PJ. Without energy efficiency improvements in the end-use sectors, the energy use would have increased by 46%. The energy efficiency improvements over this period generated approximately 1,560.4 PJ in energy savings (OEE, 2011).

8 Barriers to energy efficiency

Although energy efficiency has been identified as cost-effective in reducing energy demand and emissions of GHG, the adoption and implementation of energy efficiency measures continues to lag behind in several countries. Sanstad and Howarth (1994), Linares and Libandeira (2010), Trianni and Cagno (2012), Trianni et al. (2014), Gerarden et al. (2014), Thollander et al. (2010), and Stavins (2013), for instance, assert that many energy efficient technologies are not adopted even if it makes sense for consumers and businesses to do so based on their private costs and benefits. They maintain that decision makers 'under-invest' in energy efficient technologies relative to the predictions of engineering and economic models. Weber (1997) and Brown (2001) make a similar assertion and claim that many potential investments in energy efficiency that appear to be cost-effective remain unexploited and that these investments can prevent a significant growth in energy demand.

If energy-efficient investments are cost-effective then their implementation will yield positive benefits to society. A question that therefore needs to be answered is why the implementation of energy efficiency measures has been lagging behind. The broad answer to this question is that there are barriers to the implementation of energy efficiency measures. Some of the major barriers to energy efficiency are as follows:

1 *Cost*: in many cases realising the benefits of energy efficiency requires upfront costly investments in energy efficiency technologies. Some examples of these investments are the purchase of more efficient equipment and appliances, undertaking audits to determine the measures that are needed to improve energy performance, retrofitting buildings, and replacement of inefficient cars by more efficient ones. Where adequate financial resources are lacking and the initial costs are unaffordable, these costs will be a real barrier to the implementation of energy efficiency measures even when the energy savings over the life time of the investments could more than cover the costs. Granade et al. (2009) estimated that although the implementation of energy

efficiency measures in the US economy had the potential to yield gross energy savings worth more than $1.2 trillion, more than $520 billion for upfront investment would be required through 2020 to realise this potential. Spees and Lave (2007), Rohdin and Thollander (2006), and Rohdin et al. (2007) are categorical that limited access to capital is by far the largest barrier to energy efficiency. Young (2008) contends that financial constraints among low income households have hindered the replacement of old household appliances by newer more efficient models that can significantly reduce the demand for energy. This constitutes a strong case for policies such as subsidies, grants and tax rebates that provide financial support to enable the initial cost hurdles to energy efficiency to be overcome (Spees and Lave, 2007; Young, 2008). It also explains why the uptake of energy efficiency measures has tended to be higher where such financial support is provided (Shorrock, 1999). Zhou et al. (2010) reports that the provision of energy efficiency loans was part of the reason why China was able to limit energy demand growth.

2 *Lack of information*: to adopt and implement energy efficiency measures, users of energy need information about energy efficiency technologies and opportunities, the reliability of various energy efficiency innovations, and the estimates of the amounts of energy wasted and that could therefore be saved from the efficiency measures. Information is also needed about how the various energy efficiency measures compare with each other in terms of the costs and benefits. Obtaining such information is difficult, time consuming, and costly and tends to obscure the benefits of energy efficiency (Trianni and Cagno, 2012). This is further complicated by the fact that economic and technological changes are occurring rapidly thus necessitating frequent adjustments to energy management plans. Providing appropriate and timely information to energy users is therefore an important initiative that can significantly accelerate the uptake of energy efficiency measures. Modern sophisticated technologies such as smart meters can also contribute to this broad objective by providing users with real time information about energy usage and the best ways to invest in energy efficiency in order to reduce their overall energy costs. There is however a sense in which information about energy efficiency is a public good and will therefore not be provided in optimal amounts through competitive markets. It rationalises the active involvement of governments in facilitating more widespread adoption of energy efficiency measures through the provision of pertinent information to the concerned stakeholders.

3 *Principal-agent problems:* principal-agent problems are a major barrier to investments in energy efficiency in several contexts (IEA, 2007). They are pervasive, disbursed and complex, and arise mainly when two parties engaged in a contract have conflicting goals and different levels of information. The presence of principal-agent problems results in the misalignment of incentives faced by those who make decisions that have implications on energy efficiency and energy use. These problems also lead to situations in which users of energy are insulated from energy price signals and therefore make energy efficiency investment or energy use decisions that are not optimal (Vernon and Meier, 2012). The relationship between landlords and tenants is an example of a situation in which the principal-agent phenomena is present. Davis (2010) and IEA (2007) point out that when landlords do not pay the energy bill, they are less likely to invest in energy saving systems given that one of their goals is to minimise capital cost. On the other hand when landlords

pay energy bills, they have an incentive to invest in more energy efficient systems to reduce the energy cost. In the latter case, the tenants will be insulated from any changes in the price of energy and will be less likely to engage in behaviours that minimise energy use. Levinson and Niemann (2004) hold the view that contracts in which landlords are responsible for utilities foster greater inefficiency in the form of wasteful use by tenants. This can explain why in New York, apartments where tenants do not pay for electricity use at least 30% more electricity compared to similar apartments where the energy bills are paid by tenants (ICC, 2014). It is also the reason why owner-occupied residential buildings in general have higher levels of energy efficiency investments through measures such as better construction, better insulation, better heating and cooling systems, and more energy-efficient appliances. By designing contracts to ensure that users of energy face price signals, they can be induced to internalise the impacts of their energy use decisions and thus accelerate the adoption of energy efficiency measures.

4 *Uncertainty*: uncertainty, in general, dampens the incentives to invest and this has been the case with energy efficiency investments in many countries. Decisions on such investments which are often irreversible require estimates of the present values of the net benefits but these estimates are difficult to derive due, in part, to the fact that the future energy prices, the actual life-cycle energy savings of particular technologies, their reliability, and their payback periods are highly uncertain. Hirst and Brown (1990), Jaffe and Stavins (1994a, 1994b), Jaffe et al. (2004), and Trianni and Cagno (2012) attribute the low diffusion rates of energy conservation technologies to the uncertainty that is associated with their adoption and use. One of the results of this uncertainty is that the users of these technologies will tend to have high implicit discount rates that reduce the present values of the net benefits from the investments and renders them less attractive. Ansar and Sparks (2009) assert that due to the high uncertainty, households and firms require very high internal rates of return in order to make energy saving investments. They also assert that due to the irreversibility of energy-saving investments, the uncertainty of future payoff streams, and the anticipation by investors of future technological advances, the decision to invest in energy-saving technology can be delayed, providing option value.

5 *Pricing distortions*: energy prices are an important determinant of energy demand and investment in energy efficiency. According to economic theory achieving optimal resource allocation in energy use requires that the energy prices be equal to the social marginal cost. However, in several countries the effective energy prices are below the social marginal cost. This is because the energy prices do not fully capture the negative externalities (adverse impacts) of energy consumption on the environment, and also because final energy or fuel uses are often subsidised by governments (IMF, 2013; IEA, 2013; Schleich, 2011; Hirst and Brown, 1990). These subsidies are pervasive and distort resource allocation by encouraging excessive energy consumption, artificially promoting capital-intensive industries, reducing incentives for investment in renewable energy and energy efficiency, and accelerating the depletion of natural resources (IMF, 2013). Instituting reforms in energy pricing is a desirable policy objective and has been demonstrated to be effective in curbing the wasteful use of energy and promoting investments in energy efficiency.

9 Conclusions and policy implications

Improving energy efficiency is a critical means for addressing the energy challenges that countries face. Energy efficiency has been demonstrated to be effective in delivering to the economy and society multiple benefits such as reducing the rate of growth of energy demand, generating cost savings due to reductions in energy consumption, reducing the emissions of GHGs that contribute to climate change, reducing the need for costly investments in energy production and distribution infrastructure, improving industrial productivity and competitiveness, and improving human health and wellbeing. Energy efficiency can also stimulate economic development, moderate energy prices, create jobs, and reduce the pressure on natural resources. In Canada, there is evidence that, overall, progress has been made over time to improve the efficiency of energy use in the residential, commercial, institutional, transportation, and industrial sectors. This progress can be attributed to energy efficiency measures such as innovative technologies that improve the energy use in buildings for lighting, space heating, and space cooling; the adoption of more efficient household appliances; and the manufacture and sale of more efficient motor vehicles that have greater fuel economy. Similar progress has been made in other countries in which energy efficiency is a policy priority.

Notwithstanding the fact that energy efficiency improvements have multiple economic, social and environmental benefits, a vexing policy concern has been the continued existence of the energy efficiency gap. It is partly for this reason that energy efficiency indicators constructed from disaggregated data are required to determine how energy efficiency in specific end-use sectors is changing over time, and to assist in developing strategies for closing the energy efficiency gap. These strategies are important in overcoming the barriers to energy efficiency that include the high investment costs, the lack of information about the availability and reliability of energy-saving technologies among energy users, uncertainty about future energy prices, and the misalignment of the incentives faced by those who make decisions on energy efficiency and energy use. This overarching goal can be achieved through public policy initiatives such as provision of targeted subsidies; tax rebates and low-interest loans to accelerate the uptake of energy efficiency investments; provision of information about the available energy-saving technologies to energy users; and correcting distortions to energy prices that result in high energy consumption and sub-optimal levels of investments in energy efficiency.

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