CHAPTER 6

energy end-use efficiency

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ABSTRACT

Since the 1970s more efficient energy use in OECD countries has weakened or eliminated the link between economic growth and energy use. At the global level just 37 percent of primary energy is converted to useful energy—meaning that nearly two-thirds is lost. The next 20 years will likely see energy efficiency gains of 25–35 percent in most industrialised countries and more than 40 percent in transition economies. Dematerialization and recycling will further reduce energy intensity. Thus energy efficiency is one of the main technological drivers of sustainable development world-wide.

Energy policy has traditionally underestimated the benefits of end-use efficiency for society, the environment, and employment. Achievable levels of economic efficiency depend on a country's industrialisation, motorization, electrification, human capital, and policies. But their realisation can be slowed by sector- and technology-specific obstacles—including lack of knowledge, legal and administrative obstacles, and the market power of energy industries. Governments and companies should recognise innovations that can lower these obstacles. The external costs of energy use can be covered by energy taxes, environmental legislation, and greenhouse gas emissions trading. There is also an important role for international harmonisation of regulations for efficiency of traded products. Rapid growth in demand provides especially favourable conditions for innovations in developing countries—enabling these countries to leapfrog stages of development if market reforms are also in place.

The economic potentials of more efficient energy use will continue to grow with new technologies and with cost reductions resulting from economies of scale and learning effects. Considerations of the second law of thermodynamics at all levels of energy conversion and technological improvements at the level of useful energy suggest further potential for technical efficiency of almost one order of magnitude that may become available during this century. Finally, structural changes in industrialised and transition economies—moving to less energy-intensive production and consumption—will likely contribute to stagnant or lower energy demand per capita in these countries. ■

More efficient energy use is one of the main options for achieving global sustainable development in the 21st century.

Today more than 400,000 petajoules a year of primary energy deliver almost 300,000 petajoules of final energy to customers, resulting in an estimated 150,000 petajoules of useful energy after conversion in end-use devices. Thus 250,000 petajoules are lost, mostly as low- and medium-temperature heat. Globally, then, the energy efficiency of converting primary to useful energy is estimated at 37 percent. Moreover, considering the capacity to work (that is, the exergy) of primary energy relative to the exergy needed by useful energy according to the second law of thermodynamics, the efficiency of today's energy systems in industrialised countries is less than 15 percent. But energy efficiency can be improved—and energy losses avoided—during the often overlooked step between useful energy and energy services (figure 6.1).

One main goal of energy analysis in the context of sustainable development is to explore ways to reduce the amount of energy used to produce a service or a unit of economic output—and, indirectly, to reduce related emissions. Two questions are key: How tight is the link between final energy use and the energy service in a given end use? And what is the potential for technological and organisational changes to weaken that link in the next 10–20 years? Because the technologies used in different regions differ substantially, the potential for economic efficiency varies. Still, more efficient energy use is one of the main options for achieving global sustainable development in the 21st century.

This chapter focuses on end-use energy efficiency—that is, more efficient use of final energy or useful energy in industry, services, agriculture, households, transportation, and other areas (see figure 6.1). Supply-side energy efficiency (energy extraction, conversion, transportation, and distribution) is treated in chapters 5 and 8. Supply-side efficiency has been the focus of energy investment and research and development since the early 20th century. End-use efficiency has received similar attention only since the mid-1970s, having been proven cheaper in many cases but often more difficult to achieve for reasons discussed below.

Energy efficiency—and indirectly, improved material efficiency—alleviates the conflicting objectives of energy policy. Competitive and low (but full-cost) energy prices support economic development. But they increase the environmental burden of energy use. They also increase net imports of conventional energies and so tend to decrease the diversity of supply. Using less energy for the same service is one way to avoid this conflict. The other way is to increase the use of renewable energies (chapter 7).

Recent trends in energy intensity in countries and regions

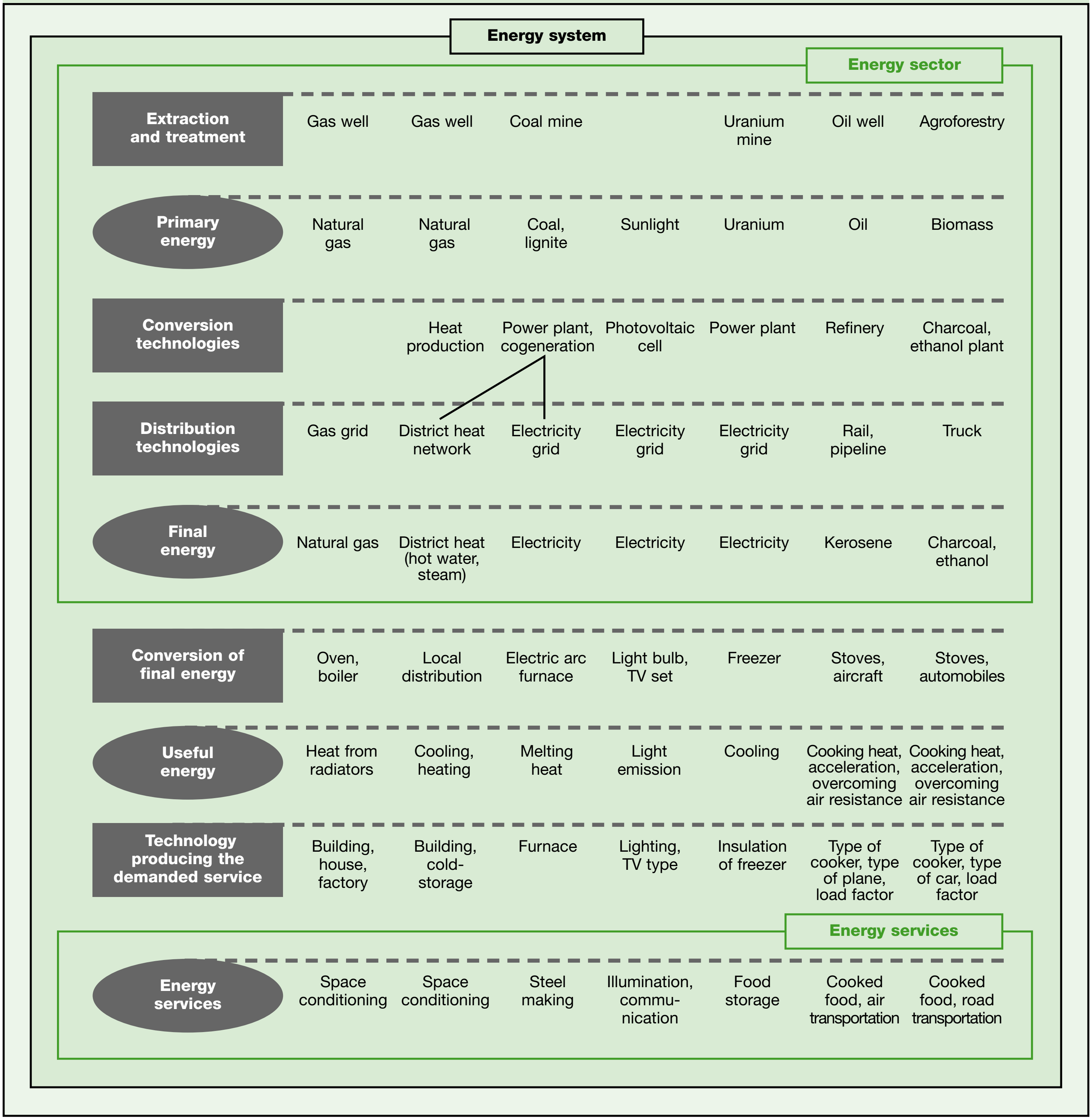
A sector's energy use, divided by gross domestic product (GDP), is the starting point for understanding differences in the efficient use of final energy by sector, country, or period. With few exceptions, such analyses have been carried out over long periods only in OECD countries (IEA, 1997a; Morovic and others, 1989; Diekmann and others, 1999). These ratios are instructive for what they say about energy use in different economies at a given point in time. They can also be used to measure changes in energy efficiency and other components of energy use—such as changes in the structure and consumption of a given sector or subsector. Changes in energy efficiency are driven by higher prices, technical improvements, new technologies, cost competition, and energy conservation programmes.

OECD countries

Over the past 30 years every OECD country and region saw a sharp decline in ratios of energy to GDP (figure 6.2; box 6.1).[1] Changes in energy use were distributed unevenly among sectors, however, and only part of the decline was related to increased energy efficiency:

- Industry experienced the largest reductions in ratios of energy to GDP—between 20 and 50 percent. Energy efficiency (if structural change is excluded by holding constant the mix of output in 1990) increased by more than 1 percent a year through the late 1980s, after which lower fuel prices caused a slowdown in improvements (Diekmann and others, 1999). In Japan, the United States, and West Germany the absolute demand for energy by industry dropped about 10 percent because of changes in the mix of products. In other countries structural changes had little impact on energy use.
- Among households, energy requirements per unit of floor area fell modestly, led by space heating. Despite far more extensive indoor heating (with more central heating), in almost all OECD countries energy use was lower in the 1990s than in the early 1970s. (The only notable exception was Japan, where income-driven improvements in heating outweighed savings from added insulation in new buildings and from more efficient heating equipment.) In addition, in most countries the unit consumption of appliances (in kilowatt-hours per year) fell. Increased efficiency outpaced trends towards larger appliances. On the structural side, however, household size continued to shrink, raising per capita energy use. New homes had larger areas per capita and more appliances, continuing an income effect dating from the early 1950s.
- Space heating in the service sector also required less energy—in heat per square metre—in most OECD countries. Electricity use remained closely tied to service sector GDP, but showed little upward trend except where electric heating was important. This outcome may be surprising given the enormous importance of electrification and office automation in the service sector. Over time there is a close relationship between electricity use and floor area.
- In passenger transportation, energy use is dominated by cars and in a few countries (such as the United States) by light trucks. In Canada and the United States in the early 1990s fuel use per

FIGURE 6.1. ENERGY CONVERSION STEPS, TYPES OF ENERGY, AND ENERGY SERVICES: POTENTIALS FOR ENERGY EFFICIENCY



Potential improvements in energy efficiency are often discussed and focused on energy-converting technologies or between the level of final energy and useful energy. But one major potential of energy efficiency, often not strategically considered, is realised at the level of energy services by avoiding energy losses through new technologies. Such technologies include new building materials and window systems, membrane techniques instead of thermal separation, sheet casting instead of steel rolling, biotechnology applications, and vehicles made of lighter materials such as plastics and foamed metals. Energy storage and reuse of break energy, along with better designs and organisational measures, can also increase energy efficiency.

kilometre by light-duty vehicles was 30 percent below its 1973 level, though by 1995 reductions had ceased (figure 6.3). Reductions ceased relative to person-kilometres because there were only 1.5 people per car in the mid-1990s, compared with more than 2.0 in 1970. Europe saw only small (less than 15 percent) reductions in fuel use per kilometre by cars, almost all of which were offset by a similar drop in load factors. Taxes on gasoline and diesel seem to be the main influence on the average efficiency of the car fleet, with the lowest taxes in the United States (averaging $0.10 a litre) and the highest in France ($0.74 a litre). For air travel, most OECD countries experienced more than a 50 percent drop in fuel use per passenger-kilometre due to improved load factors and increased fuel efficiency. Higher mobility per capita and shifts from trains, buses, and local transport towards cars and air travel, however, counterbalanced the efficiency gains in most countries.

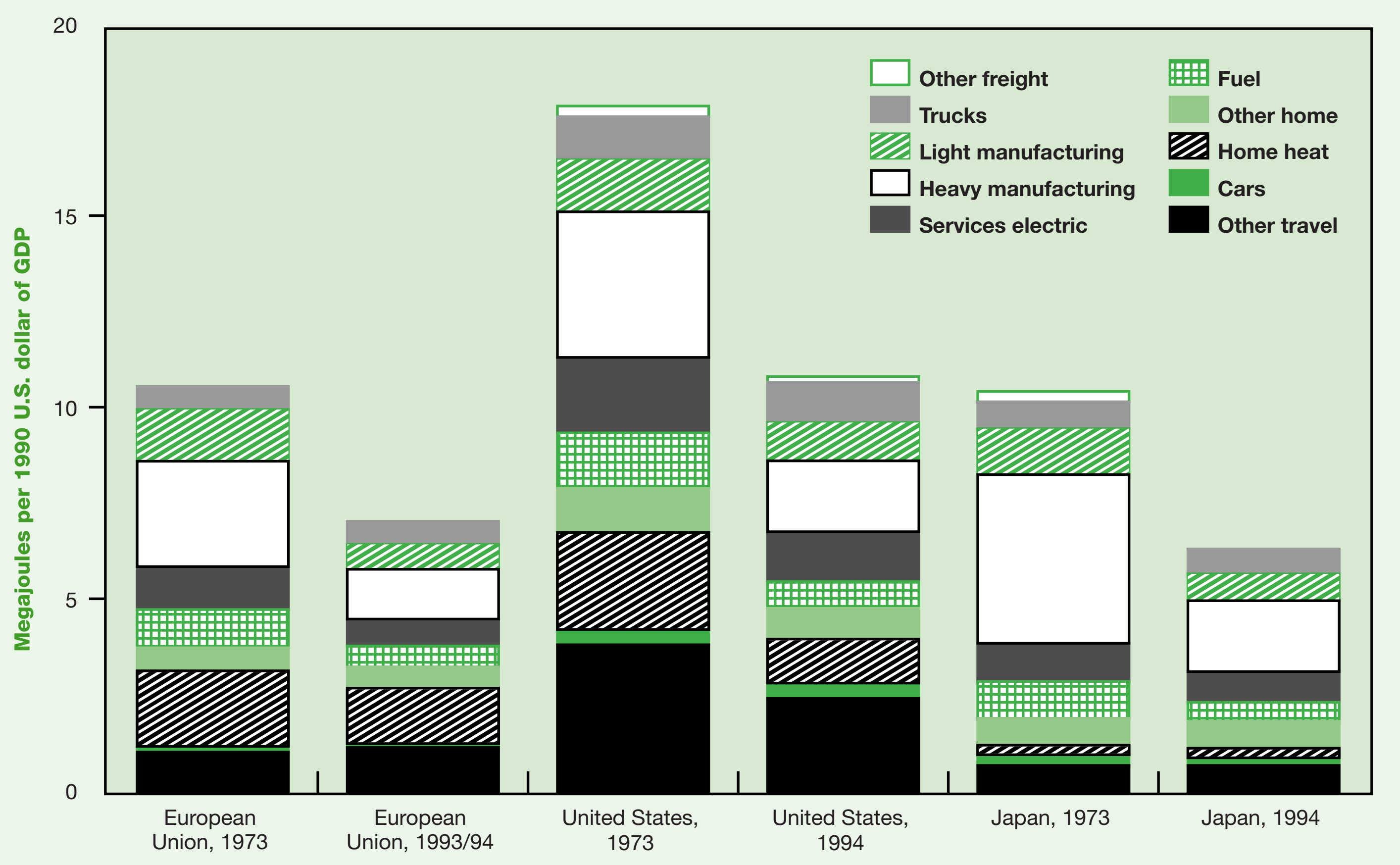
- Freight transport experienced rather small changes in energy use per tonne-kilometre. Improvements in fuel efficiency were offset by a shift towards trucking. This shift was driven by higher GDP, less shipping of bulk goods by rail and ship, and more lifting of high-value partially manufactured and final goods by trucks and aeroplanes.

In most OECD countries energy intensities fell less rapidly in the 1990s than before. One clear reason—besides higher income—was lower energy prices since 1986 and lower electricity prices (due to the liberalisation of the electricity market in many OECD countries), which slowed the rate of energy efficiency improvement for new systems and technologies.

Eastern Europe and the Commonwealth of Independent States

Relative to OECD countries, the statistical basis for ratios of energy to GDP is somewhat limited in Eastern Europe and the Commonwealth of Independent States.[3] Ratios of primary energy demand to GDP have risen in the Commonwealth of Independent States since 1970 (Dobozi, 1991) but began to decline in many Eastern European countries in the mid-1980s (table 6.1). General shortcomings of central planning, an abundance of energy resources in some countries, a large share of heavy industries, low energy prices, and a deceleration of technological progress have been the main reasons for limited progress (Radetzki, 1991; Dobozi, 1991; Sinyak, 1991; Gritsevich, 1993).

FIGURE 6.2. RATIOS OF ENERGY TO GDP IN OECD COUNTRIES BY END USE, 1973 AND 1994



Note: Measured using purchasing power parity.

Source: Schipper, 1997.

BOX 6.1. DRIVERS OF LOWER ENERGY DEMAND: DEMATERIALIZATION, MATERIAL SUBSTITUTION, SATURATION, AND CHANGING BEHAVIOUR

Like ratios of energy to GDP, the production of energy-intensive materials per unit of GDP is falling in almost all industrialised countries (with a few exceptions such as Australia, Iceland, and Russia). Changes in the production of basic materials may affect changes in ratios of energy to GDP. In many OECD countries declining production of steel and primary aluminium is supporting lower ratios of energy to GDP. But production of young, energy-intensive materials—such as polymers substituting for traditional steel or aluminium use—is increasing relative to GDP. In addition, ratios of energy-intensive materials to GDP are increasing slightly in developing countries, almost balancing out the declines in industrialised countries for steel and primary aluminium over the past 25 years.

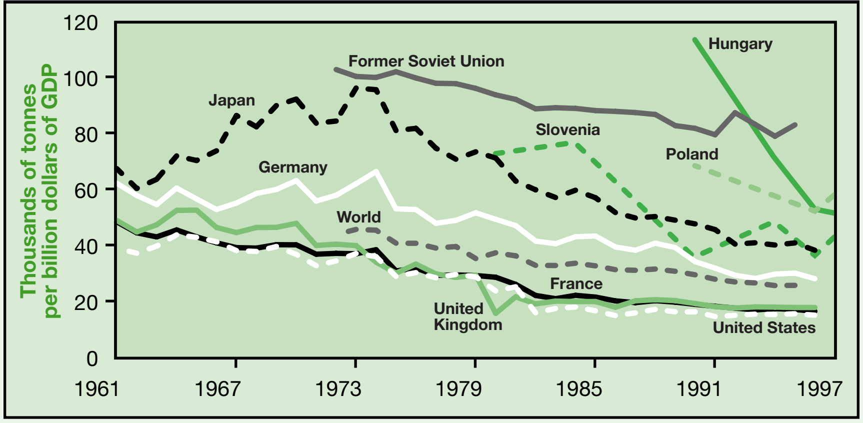
Dematerialization has different definitions covering the absolute or relative reduction in the quantity of material used to produce a unit of economic output. In its relative definition of tonnes or volumes of material used per unit of GDP, dematerialization has occurred over several decades in many industrial countries. This shift has contributed to structural changes in industry—particularly in energy-intensive areas such as chemicals and construction materials (Carter, 1996; Jaenicke, 1998; Hinterberger, Luks, and Schmidt-Bleek, 1997).

A number of forces are driving dematerialization in industrialised countries (Ayres, 1996; Bernadini, 1993):

- As incomes rise, consumer preferences shift towards services with lower ratios of material content to price.
- As economies mature, there is less demand for new infrastructure (buildings, bridges, roads, railways, factories), reducing the need for steel, cement, non-ferrous metals, and other basic materials.
- Material use is more efficient—as with thinner car sheets, thinner tin cans, and lighter paper for print media.
- Cheaper, lighter, more durable, and sometimes more desirable materials are substituted—as with the substitution of plastics for metal and glass, and fibre optics for copper.
- Recycling of energy-intensive materials (steel, aluminium, glass, paper, plastics, asphalt) contributes to less energy-intensive production. Recycling may be supported by environmental regulation and taxes (Angerer, 1995).
- Reuse of products, longer lifetimes of products (Hiessl, Meyer-Krahmer, and Schön, 1995), and intensified use (leasing, renting, car sharing) decrease new material requirements per unit of service.
- Industrialised countries with high energy imports and energy prices tend to decrease their domestic production of bulk materials, whereas resource-rich developing countries try to integrate the first and second production steps of bulk materials into their domestic industries (Cleveland and Ruth,1999).

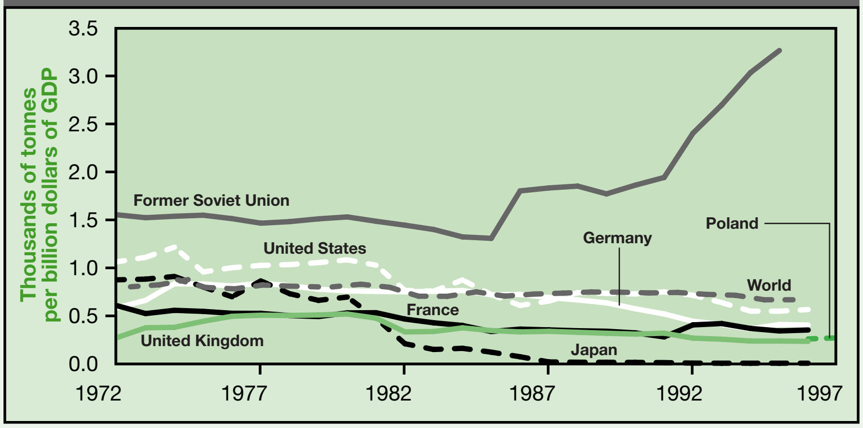
But industrialised countries are also experiencing some of the drivers of increased material use per capita. Increasing urbanisation, mobility, and per capita incomes increase the demand for material-intensive infrastructure, buildings, and products. Smaller households, the increasing importance of suburban communities and shopping centres, and second homes create additional mobility. The move from repair to replacement of products and trends towards throwaway products and packaging work against higher material efficiencies—and, hence, against energy efficiency and sustainable development.

Steel production intensity in various countries, 1961–96



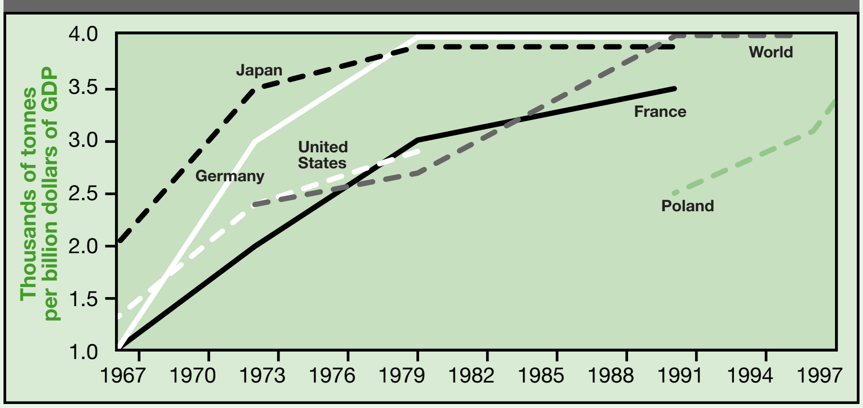
Source: IEA, 1998; Wirtschaftvereinigung Stahl, 1998.

Primary aluminium production intensity in various countries, 1972–96



Source: IEA, 1998.

Polymer production intensity in various countries, 1966–97



Note: For the world, includes all plastics. For France, Germany, Japan, and the United States, includes only polyethylene, polypropylene, polystyrene, and polyvinylchloride.

Source: UN, 1999; German Federal Statistical Office; IEA 1998.

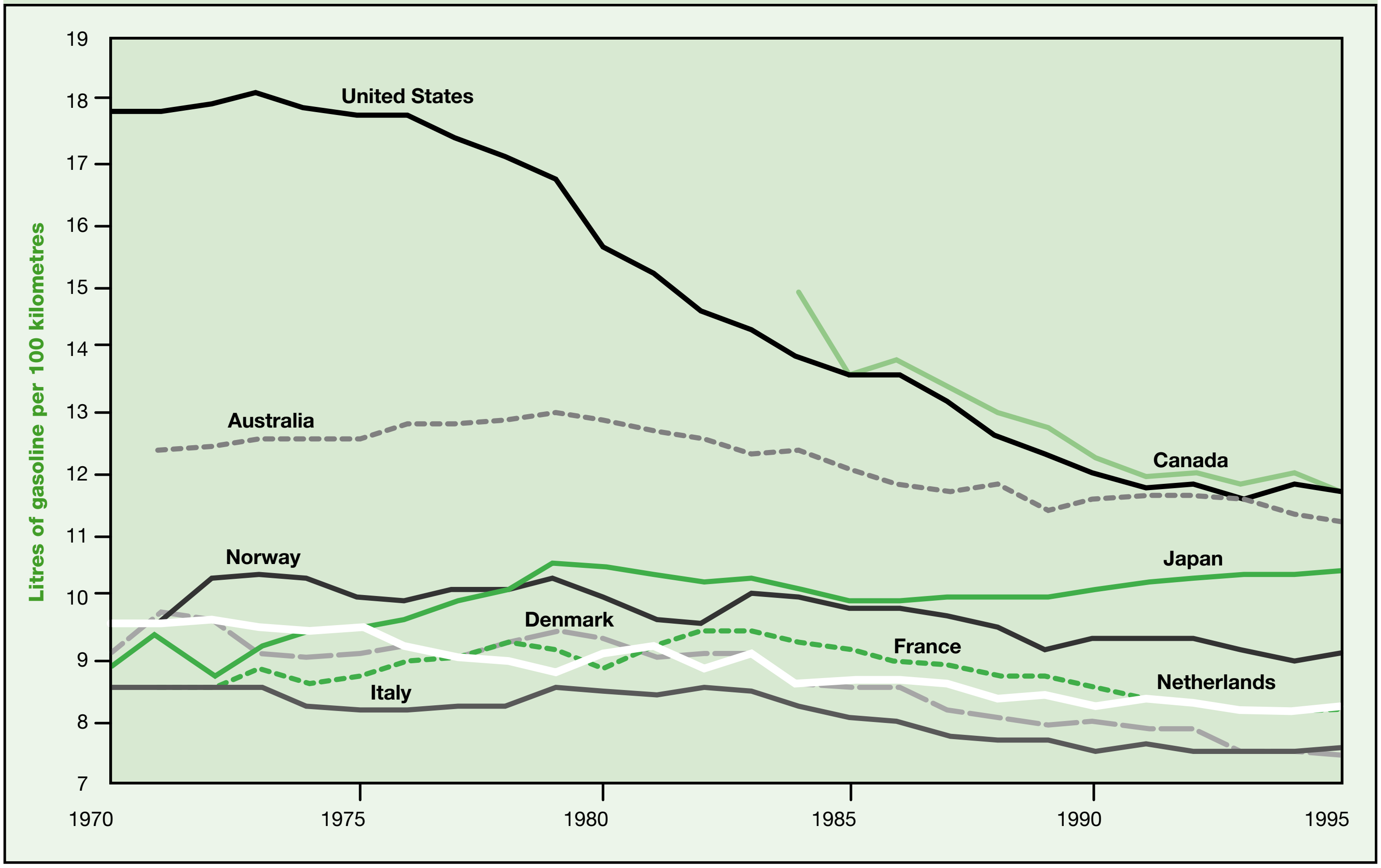
Ratios of primary energy to GDP have gone through two phases in these countries, separated by the onset of economic and political reform in the late 1980s and the 1990s. Whereas the ratio increased in Russia, it declined in Armenia, Belarus, Estonia, Kyrgyzstan, Latvia, and Tajikistan. Among the other members of the Commonwealth of Independent States the ratio fluctuated for reasons other than improvements in energy efficiency (IEA, 1997a, 1998). Since 1990 the ratio has declined in most Eastern European countries (see table 6.1).

- In industry, final energy consumption per unit of output fell less than 1 percent a year in Eastern Europe in 1990–97 but increased almost 7 percent a year in Russia (CENEf, 1998).
- Transportation saw few changes in energy use per passenger-kilometre or tonne-kilometre for the two main modes, cars and trucks.
- Among households, small gains in the thermal integrity of buildings could not overcome increasing demands for heating and comfort. Indeed, in the mid-1980s centrally heated Eastern European buildings required 50–100 percent more final energy per unit of area and per degree day (that is, using standardised winter outdoor temperatures) than similar buildings in Western Europe. Moreover, home appliances were often small and inefficient.

In the early 1990s economic reforms began to restructure production and consumption patterns and raise once-subsidised energy prices. In the Baltics, the Czech Republic, Hungary, and Poland this phase led to real declines in ratios of primary energy to GDP as efficiency increased and the structure of manufacturing changed (see table 6.1). Several transition economies also saw lower household fuel use for space and water heating. Such changes were often not related to efficiency, however, and were instead caused by energy shortages, higher energy prices, and related changes in heating behaviour.

Overall, transition economies showed a remarkable contraction in energy use by industry, mostly because of structural changes (Bashmakov, 1997a). But this trend has nearly been outweighed by rapid growth in road transportation and (in some countries) in electricity for appliances and services. Structural changes in industry, integration with global markets, and investments in new processes, buildings, and infrastructure are expected to improve energy efficiency considerably over the next 20 years. These trends will likely help stabilise energy demand despite rising incomes and GDP in these countries.

FIGURE 6.3. WEIGHTED AVERAGE OF ON-ROAD AUTOMOBILE GASOLINE AND DIESEL FUEL INTENSITIES IN OECD COUNTRIES, 1970–95



Source: Schipper, 1997.

Developing Asia, Africa, and Latin America

In many developing countries energy use will be driven by industrialisation, urbanisation, increasing road transportation, and increasing personal incomes.[4] Indeed, 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. Wide income disparities in many developing countries are also reflected in energy consumption patterns. Often a small portion of the population accounts for most commercial energy demand. Data limitations hamper careful analysis in many developing countries, however.

Higher-income developing countries (per capita income above $1,200 in 1998 purchasing power parity terms). Energy demand in industry has fallen in most higher-income developing countries, both as a result of higher energy prices in the 1970s and 1980s and open borders to international competition. China has shown the most dramatic developments, but most Latin American and other Asian economies have also shown energy intensity improvements in this sector. 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

TABLE 6.1. RATIOS OF PRIMARY ENERGY TO GDP IN TRANSITION ECONOMIES, 1985–96

Region/country	Energy consumption per capita, 1996 (gigajoules)	Megajoules per unit of GDP (1990 purchasing power parity dollars)		
		1985	1990	1995
Commonwealth of Independent States	**135**	**29.8**	**29.4**	**41.4**
Belarus	100			20.5
Russia	170			36.8
Ukraine	127			45.2
Eastern Europe	**89**[a]	**23.9**	**21.8**	**20.9**
Bulgaria	120	36.0	29.7	31.8
Czech Republic	165	23.6	19.6	18.2
Hungary	108	18.3	16.5	16.3
Poland	117	26.5	21.6	19.2
Romania	84	28.5	31.8	25.1
Slovenia[b]	124		12.6	13.8
Former Yugoslavia	53[a]	12.6	14.7	21.4

a. Data are for 1995. b. Based on exchange rates.

Source: IEA, 1997a, Kos, 1999.

TABLE 6.2. RATIOS OF PRIMARY ENERGY TO GDP IN DEVELOPING COUNTRIES, 1975–95

Country or region	Energy consumption per capita, 1996 (gigajoules)	Megajoules per unit of GDP (1990 purchasing power parity dollars)				
		1975	1980	1985	1990	1995
China	36.3[a]	23.4	22.6	17.3	15.0	10.9
India	14.6[a]	7.5	7.8	8.3	8.7	9.2
Indonesia	18.4	3.3	4.2	4.6	5.4	5.4
Argentina	64.1	8.0	8.4	9.2	9.6	9.6
Brazil	61.0[a,b]	4.6	4.6	5.0	5.4	5.9
Mexico	61.4	7.2	8.2	8.5	8.7	8.7
Venezuela	94.0[a]	10.5	11.3	12.6	12.1	12.1
North Africa[c]	29.2	5.4	6.3	7.9	8.8	9.4
Southern Africa[d]	27.4	10.8	11.6	15.2	13.9	14.4
Rest of Africa	2.5	2.6	2.9	2.6	2.6	2.9
Middle East	80.4	8.4	10.9	17.6	20.9	22.6

a. Data are for 1996. b. Includes non-commercial energy. c. Ratios of energy to GDP are for Algeria, Egypt, Libya, Morocco, and Tunisia. d. Ratios of energy to GDP are for Nigeria, South Africa, Zambia, and Zimbabwe.

Source: EC, various years; IEA, 1998.

regulation, and lower overhead and transportation costs. Many of these countries (Brazil, China, India, Indonesia) also need their own basic product industries.

Household appliances, cookers, and water heaters have become more energy efficient in higher-income developing countries. But the rapid acquisition of household devices has far outpaced the impact of greater efficiency.

A similar trend has occurred in the service and public sectors. Buildings in warm higher-income developing countries have increasing rates of air conditioning. Higher lighting levels, increased office automation, and other developments have also contributed to rapidly rising electricity use in this sector (IEA, 1997b).

Transportation accounts for a rising share of energy use in higher-income developing countries. Growing numbers of vehicles, often rising at 1.5 times the rate of GDP growth, have dominated the transportation energy use picture. Many cars and light trucks sold in the developing world have become less fuel intensive. But increased urbanisation and traffic congestion and reduced occupancy have eaten up many of the improvements in vehicle technology.

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). Increasing numbers of cars and trucks, electrification of rural areas, and increased energy use by households have played a bigger role (table 6.2). Such energy uses were hardly mature before the 1970s. Motor vehicles and household appliances were far more expensive, in real terms, than they are today. Today such items are less costly and, more important, are often made in developing countries. (China is an exception to this pattern. In 1978, when it initiated economic reform, China exploited economies of scale in manufacturing—such as steel-making—to realise high efficiency improvements in industry and energy.)

Lower-income developing countries (per capita income below $1,200 in 1998 purchasing power parity terms). The situation in lower-income developing countries is somewhat different.

- When disposable income increases, energy consumption by households in low-income developing countries shifts from traditional to commercial fuels. This trend has significant implications for energy efficiency in households. Since the technical efficiencies of cooking appliances using commercial fuels are higher than those of biomass, composite energy consumption per household tends to fall. A typical example is the move from a fuelwood stove with a technical efficiency of 12–18 percent to a kerosene stove with an efficiency of 48 percent, or to a liquefied petroleum gas stove with an efficiency of 60 percent. On the other hand, the substitution of commercial for traditional fuels raises ratios of energy to GDP, because traditional energy is typically not included when such ratios are calculated. In addition, electrification in rural areas and increasing income and mobility in urbanising areas increase energy use.
- Most of the technology used by industry in lower-income developing countries is imported from industrialised countries. Thus these industries should continue to benefit from technological improvements that promote rational energy use (see below). While this is expected to make energy demand fall, the use of obsolete and energy-inefficient technology imported from industrialised countries will drive the specific energy demand of industry.
- Similarly, the transportation sector should benefit from the global trend towards improving vehicle fuel efficiency. Because lower-income developing countries import vehicles from other countries, the energy intensity of road transport should decrease. But the large share of used vehicles imported by lower-income developing countries is helping to maintain a relatively old car stock with high specific fuel demand.

In many developing countries energy use will be driven by industrialisation, urbanisation, increasing road transportation, and increasing personal incomes.

Energy intensity in lower-income developing countries will largely depend on the interplay between these factors. Although available data (which are patchy at best) show that, for example, Africa's ratio of energy to GDP increased by 1.8 percent a year in 1975–95, that trend may be substantially influenced by the substitution of commercial for non-commercial forms of energy.

Potential benefits of technology transfer

In many cases used factories, machines, and vehicles from industrialised countries are transferred to developing or transition economies, saddling them with inefficient equipment and vehicles for many years.[5] The transfer of energy-efficient equipment and vehicles to developing and transition economies offers an important opportunity for leapfrogging the typical development curves of energy intensity and for achieving sustainable development while maximising know-how transfer and employment opportunities. The transfer of energy-efficient technology represents a win-win-situation for the technology provider and the recipient. Benefits on the receiving end include reduced energy imports, increased demand for skilled workers, job creation, reduced operating costs of facilities, and faster progress in improving energy efficiency. The scope for improving energy efficiency through technology transfer can be seen by comparing energy uses in various industries and countries (table 6.3).

TABLE 6.3. FINAL ENERGY USE IN SELECTED INDUSTRIES AND COUNTRIES, MID-1990S (GIGAJOULES PER TONNE)

Country	Steel	Cement	Pulp and paper
India	39.7	8.4	46.6
China	27.5–35.0	5.9	
United States	25.4	4.0	40.6
Sweden	21.0	5.9	31.6
Japan	17.5	5.0	

Source: Lead authors.

Used equipment and vehicles are traded for lack of capital, lack of life-cycle costing by investors, the investor-user dilemma (see below), and lack of public transportation in developing countries (President's Committee of Advisors on Science and Technology, 1999, p. 4-3; IPCC, 1999b). Thus high efficiency standards for products, machinery, and vechicles in OECD countries will also affect standards in developing and transition economies, particularly for mass-produced and tradable products and for world-wide investments by global players. Opportunities for technology transfer among developing countries will also become more important and should be encouraged. Many of these countries already have well-established domestic expertise and produce goods, technologies, and services suitable for the conditions and climates of other developing countries.

Many developing countries do not have the infrastructure needed to study and evaluate all the technological options that might suit their needs.

Transition economies

About 40 percent of the fuel consumed in transition economies is used in low-temperature heat supply. Slightly less than half of that heat is directed by district heating systems to residential buildings, public services (schools, kindergartens, hospitals, government agencies), and commercial customers (shops and the like). District heating systems exist in many cities containing more than 20,000 people. In many transition economies a significant share of the building stock (about 20 percent in Hungary) was built using prefabricated concrete panels with poor heat insulation and air infiltration.

Advanced Western technology (automated heat distribution plants, balancing valves, heat mirrors, efficient taps, showerheads, heat-reflecting layers of windows) offers significant potential for more efficient heat use in buildings (Gritsevich, Dashevsky, and Zhuze, 1997). Such technology can save up to 30 percent of heat and hot water and increase indoor comfort. Among the main advantages of Western products are their reliability, efficiency, accuracy, design, and sometimes competitive prices. Some Western companies have launched joint ventures with Eastern European, Ukrainian, and Russian partners or created their own production lines using local workers. In many cases this seems to be a better option than imports, because underemployed factories and human capital may otherwise induce conflicts of interest.

Many transition economies have developed advanced energy-efficiency technology (powder metallurgy, variable-speed drives for super-powerful motors, fuel cells for space stations, plasmic technologies to strengthen working surfaces of turbine blades). Thus the greatest benefits can be gained when domestic technology and human capital and an understanding of local conditions are combined with the best Western technology and practices.

Developing countries

Despite the many positive implications of transferring energy-efficient technology, some major issues need to be addressed to fully exploit the potential benefits to developing countries (UNDP, 1999):

- *Proper technology assessment and selection.* The technology transfer process must help user enterprises evaluate their technological options in the context of their identified requirements (TERI, 1997a). Developing countries are at a great disadvantage in selecting technology through licensing. Companies develop technology mainly to suit their current markets; technology is not necessarily optimised for the conditions in recipient countries. Many developing countries do not have the infrastructure needed to study and evaluate all the technological options that might suit their needs. Moreover, an enterprise trying to sell a technology to a developing country will rarely give complete and unbiased advice. So, there is an urgent need to develop an information support system and institutional infrastructure to facilitate the selection of appropriate technologies. In India, for example, a Technology Development Board was established in 1996 to facilitate the assimilation and adaptation of imported technology (CMIE, 1997).
- *Adaptation and absorption capability.* Technology transfer is not a one-time phenomenon. The transferred technology needs to be updated from time to time, either indigenously or through periodic imports. Moreover, lack of local capability can result in the transferred technology seldom reaching the designed operational efficiency, and often deteriorating significantly. This raises the need for local capacity building to manage technological change. In a narrower sense, this could be facilitated by policies requiring foreign technology and investment to be accompanied by adequate training of local staff (President's Committee of Advisors on Science and Technology, 1999).
- *Access to state-of-the-art technology and to capital.* In many cases transferred technology is not state of the art, for several reasons. First, enterprises in industrialised countries need to recover the costs of technology development before transferring the technology to other countries, introducing a time lag in the process. Second, in some developing countries there is a demand lag for the latest technology due to factors such as lack of capital or trained staff. Third, there are inappropriate technology transfers because of the higher costs of acquiring state-of-the-art technology. A lack of capital and strong desire to minimise investment costs have often led developing countries to import obsolete used plants and machinery.
- *The problems of small and medium-sized enterprises.* Small industrial enterprises account for a large share of energy and technology use in many developing countries. These enterprises may play an important role in the national economy but generally remain isolated from or ignorant of the benefits of technology upgrading. For such enterprises, where off-the-shelf solutions are seldom available, knock-down technology packages from industrialised countries are rarely possible. An important element of technology transfer for this group is proper competence pooling to arrive at appropriate technology solutions.

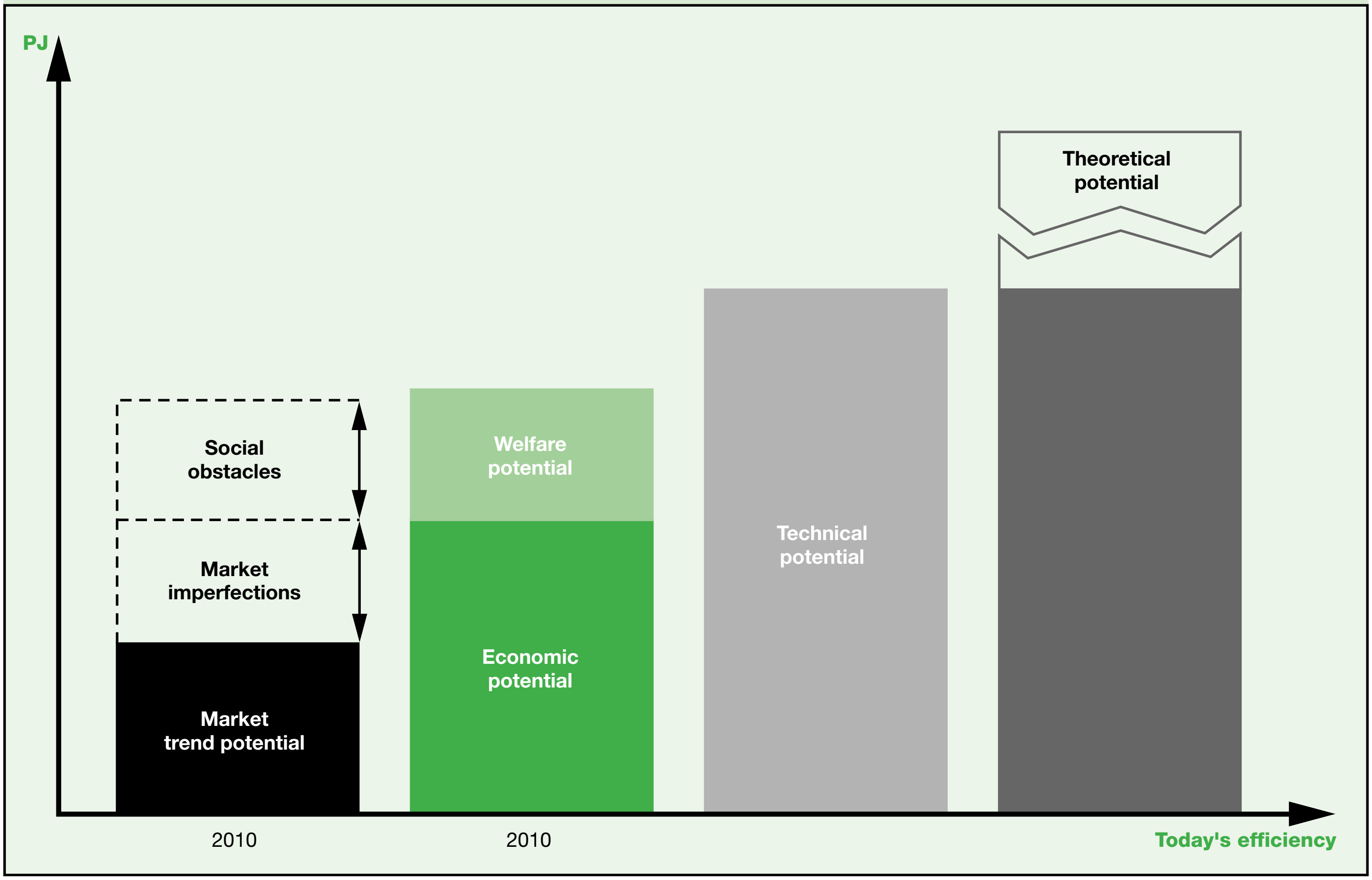
Again, the situation differs between higher- and lower-income developing countries. Several countries in Latin America and Southeast Asia are producing highly efficient technology and vehicles—electrical motors, refrigerator compressors, cars—through local companies or subsidiaries of multinational companies. Control systems, super-efficient windows, and new materials that improve the thermal insulation of buildings may offer further opportunities for technology transfer to higher-income developing countries (Hagler Bailley Services, 1997).

Types of potential for increased energy efficiency

As noted, the global energy efficiency of converting primary to useful energy is estimated to be 37 percent.[6] But the useful energy needed for a desired energy service will likely fall. Estimated improvements are based on known technologies, expected costs, consumer behaviour, market penetration rates, and policy measures. When considering the potential for increased energy efficiency, it is essential to distinguish between several types of potential, each describing future technological achievements with different time horizons and boundary assumptions (as well as level of analysis in the case of economic potential). This report uses the following definitions (Enquête Commission, 1991; IEA; 1997a; figure 6.4):

- The theoretical potential represents achievable energy savings under theoretical considerations of thermodynamics where energy services (such as air conditioning and steel production) are kept constant but useful energy demand and energy losses can be minimised through process substitution, heat and material reuse, and avoided heat losses (see section below on theoretical potentials after 2020).
- The technical potential represents achievable energy savings that result from implementing the most energy-efficient commercial and near-commercial technology available at a given time, regardless of cost considerations and reinvestment cycles. This can be expressed as a phased-in potential that reflects the total replacement of existing energy-converting and -using capital stocks.
- The market trend potential—or expected potential—is the efficiency improvement that can be expected to be realised for a projected year and given set of boundary conditions (such as energy prices, consumer preferences, and energy policies). The market trend potential reflects obstacles and market imperfections that keep

FIGURE 6.4. THEORETICAL, TECHNICAL, ECONOMIC, AND MARKET TREND POTENTIALS OF ENERGY EFFICIENCY



Source: Enquête Commission, 1991.

efficiency potentials from being fully realised (see the section below on obstacles).
- The economic potential is the energy savings that would result if during each year over the time horizon in question, all replacements, retrofits, and new investments were shifted to the most energy-efficient technologies that are still cost-effective at given energy market prices. It also includes all organisational measures such as maintenance, sensitive operation and control, and timely repairs. The economic potential has subdefinitions depending on the economic perspective being used: the business (or project) perspective, the macroeconomic perspective, or the societal (or welfare-based) perspective (box 6.2). The economic potential implies a well-functioning market, with competition between investments in energy supply and demand. It also assumes that the barriers to such competition have been corrected by energy policies. It is assumed that as a result of such policies, all users have easy access to reliable information about the cost-effectiveness and technical performance of existing and emerging options for energy efficiency. The transaction costs for individual investors, and the indirect costs of policies associated with implementing these options, are assumed to have been lowered to their irreducible minimum.
- The societal (or welfare-based) potential represents 'cost-effective' savings when externalities are taken into consideration. These include damage or avoided damage costs from health impacts, air pollution, global warming, and other ecological impacts, as well as energy-related occupational accidents that accrue to society. This wider definition of cost-effectiveness is the most important for a holistic energy policy that includes energy security and environmental quality (OTA, 1993).
- Finally, the policy-based achievable potential represents the energy savings that can be realised with various policy instruments or packages of policy instruments. Here field data are used to estimate participation rates and per participant savings in voluntary or standards-based technology programmes. The policy-based achievable potential lies between the market trend potential and the economic potential (which can be influenced by energy taxes).

This chapter focuses on the economic potential. The economic perspective underlying the potentials reported here, however, varies by study. Most current estimates are based on a business (financial) perspective, though there are also hybrids that use a macroeconomic perspective (see box 6.2). Quantitative comparisons between business and macroeconomic efficiency potentials suggest that microeconomic approaches underestimate the cost-effective savings potential (Krause, 1996). Similarly, macroeconomic approaches underestimate cost-effective savings potentials relative to a societal perspective.

> Achieving two benefits of increased energy efficiency—positive economic effects and reduced environmental burden—is called a 'double dividend'.

BOX 6.2. DIFFERENT PERSPECTIVES ON THE ECONOMIC POTENTIAL OF ENERGY EFFICIENCY

In all definitions of the economic potential of energy efficiency, the core cost-effectiveness test is the life-cycle cost of providing a given level of energy services. Different definitions of the economic potential arise because of different cost-benefit perspectives. These perspectives influence how costs and financial parameters are defined and whether policy-dependent implementation costs or reductions in external costs are included.

The economic potential at the business level is calculated from the perspective of an individual investor based on engineering and economic life-cycle costs, using a financial perspective. In this narrowest of all definitions, total costs consist of the levelised capital costs of energy efficiency investments plus changes in annual energy and non-energy operation and maintenance costs. Neither the costs of large-scale policy implementation nor the cost savings from policy-induced feedback effects are attached to this potential. The discount rate for evaluating the cost-effectiveness of energy efficiency investments is typically set to reflect the costs of capital of particular sectors, industries, or households. After-tax energy efficiency investments are compared to after-tax average energy prices as projected for each sector or group of energy users.

The macroeconomic potential is based on a more comprehensive accounting of costs and on a different financial perspective. Here the administrative costs of implementing various required policies are included. In addition, energy efficiency investment costs and policy implementation costs are corrected in a forward-looking manner to account for changes in manufacturer pricing strategies, economies of scale, and learning effects.

The economic potential of energy efficiency by region and sector

Economic potentials of energy efficiency depend on current and foreseeable technology developments and on current and anticipated energy prices (box 6.3). In a world of low energy prices, the potential is relatively small. But high energy prices could be achieved through energy taxes at a national, regional, or global level. The economic potential presented below for each region is based on the energy prices assumed in the literature. Calculations of the economic potential of energy efficiency cover different technologies:
- The potential of mono-functional and concise energy-converting technology (boilers, heat exchangers, electrical motors) is usually determined by standard profitability calculations comparing the full costs of alternative and statistically relevant conversion technology.
- Process substitution and new building concepts or transportation systems include other changes in economic efficiency (capital, labour, and so on) and in product or service quality. Here it becomes difficult to talk about the profitability of the technology in the narrow sense of energy efficiency if the new, higher-efficiency technology is considered competitive in the broader sense (as with new catalysts in the production of petrochemicals, separation by membranes instead of energy-intensive distillation, or low-energy houses instead of conventional houses).
- Branch-specific but technology-clustered energy efficiency potentials of low energy-intensive sectors in industry or the commercial sector are estimated by trend extrapolation of statistical data or by generalisation of calculations made for representative or typified

plants or factories. To avoid misinterpretation, data on branch-specific energy efficiency potentials should not include intrabranch structural changes (such as a shift of high value added but low energy-intensive pharmaceuticals to higher shares of total value added in the chemical industry).

These different cost assessments may help explain the differences in certainty about the economic potentials cited below. The data on economic potentials provide projections for 2010 and 2020. This means that where reinvestment cycles last more than 20 years (as with buildings, public transport, and plants of basic product industries), the economic potentials are only partly realised by 2020. The sectors and technological areas discussed in this section were chosen based on the relevance of the efficiency technology and the availability of the literature for the region or country considered.

Deviations from a given economic potential reflect changes in energy prices, economies of scale, or local differences. In many cases the life-cycle cost functions have rather broad minima (such as optimal insulation thickness), which means that there is little risk of overinvesting in energy efficiency or of overestimating the cited potentials.

Western Europe

Industry. Until the early 1990s industry was the largest consumer of final energy in Western Europe.[8] But despite production growth of about 2 percent a year, the final energy demand of Western European industry has hovered near 11,500 petajoules for the past 20 years. Yet industry still holds substantial economic efficiency potential, even in energy-intensive sectors where investment has focused on efficiency improvements to lower high energy costs (Phylipsen, Blok, and Worrell, 1998).

- De Beer (1998, pp. 75–102) estimates that by 2020 paper mills operating with new pressing and drying techniques, latent heat recovery systems, and a number of minor improvements (closed water circulation, graduated heat recovery) will have 50 percent lower specific heat demand and that investment costs may be lower than for conventional paper-making (table 6.4). The economic efficiency potential of steel-making is less extraordinary, between 13 and 20 percent, and results from thin slab casting, more efficient blast furnaces, and minor improvements in the oxygen steel process by 2020 (Jochem and Bradke, 1996). Similar economic efficiency potential has been described for refineries (Refining Processes, 1998), petrochemical processes (Patel, 1999) and basic organic chemicals (Brewer and Lopez, 1998), construction materials (Rosemann and Ellerbrock, 1998; Ottoboni and others, 1998), glass production (ATLAS, 1997), and the food industry (Jochem and Bradke, 1996).
- For Dutch light industry, the economic efficiency improvements in 2000 (relative to 1990) are estimated at 30 percent (with a 5 percent discount rate) and 27 percent (with a 10 percent discount rate; Blok and others, 1996; Böde and others, 1999).
- Baumgartner and Muggli (1996) evaluated the efficiency improvements of cross-cutting technologies in Swiss industry. Savings of 15–35 percent were found for electrical and mechanical drives over the next 10–15 years (Almeida, Bertoldi, and Leonhard, 1997). Metering, controlling, and optimal regulation can lead to efficiency improvements of up to 15 percent in most industrial processes. Cogeneration in Western Europe still holds economic potential, particularly with the midterm effects of liberalising electricity supply and small cogeneration (ATLAS, 1997; EC, 1999).

Residential. The economic efficiency potential in heating of residential buildings depends—besides regional aspects—on the stock of boilers and their reinvestment cycles, the rate of constructing new buildings, and the rate of refurbishing existing buildings. Condensing boilers are about 10 percent more energy efficient than a new low-temperature boiler and 15–25 percent more efficient than existing boilers (Ziesing and others, 1999). Insulation of building elements, highly efficient window systems, and adequately thick insulation are economic within the cycle of refurbishment (ETSU, 1994). In new buildings, low-energy houses (those with annual heat demand of 50–100 kilowatt-hours per square metre) are now cost-effective due to

BOX 6.3. ECONOMIC BENEFITS OF INCREASED ENERGY EFFICIENCY IN END USES—THE UNKNOWN DOUBLE DIVIDEND

Energy consumers benefit when profitable energy efficiency potentials are realised.[7] But the economy also benefits, because saved energy costs can be reallocated, energy imports are replaced (in many countries) by domestically produced energy-efficient products and (energy) services, and labour-intensive branches can grow in industry, construction, and services (instead of capital-intensive energy supply), spurring innovation. Macroeconomic analyses for Germany and the United States show that policies to improve energy efficiency and to shift to advanced technology and less carbon-intensive fuels generate four important benefits for the national economy (Jochem and Hohmeyer, 1992; Laitner, Bernow, and DeCicco, 1998). Such policies:

- Spur economic growth to a small degree (by less than 1 percent of the absolute growth rate of GDP) due to the reallocation of saved energy costs.
- Generate jobs (including entrepreneurial jobs that foster resourceful, self-sufficient, and satisfied workers) for the reasons mentioned above. Net employment increases by 40–60 new jobs per petajoule saved each year.
- Increase exports of high-technology products. In 1976–92 exports of 12 energy-efficient products increased more than 50 percent faster than West Germany's total exports.
- Reduce the environmental and social costs of energy use that were previously uncounted in market transactions for fuel. Such costs may be as high as $0.02 per kilowatt-hour of electricity (Friedrich and Krewitt, 1997) and almost $0.01 per kilowatt-hour of oil product used, not including the impacts of climate change (Hohmeyer, Ottinger, and Rennings, 1997).

Achieving two benefits of increased energy efficiency—positive economic effects and reduced environmental burden—is called a 'double dividend'. Unlike many other employment effects of investment, the jobs created by efficiency investments are not evenly distributed over time. In most cases they are created during the initial period of investment—when wall insulation is installed or investments are made in condensing boilers or high-efficiency window systems. In addition, the regional distribution of net employment becomes more equitable. Employment in the energy supply sector is concentrated in urban and industrial areas, while efficiency involves planners, crafts, trade, and banking in the entire country.

TABLE 6.4. ECONOMIC ENERGY EFFICIENCY POTENTIALS IN WESTERN EUROPE, 2010 AND 2020

Sector and technological area	Economic potential (percent)[a] 2010	Economic potential (percent)[a] 2020	Energy price level assumed	Base year	Source
Industry					
Iron and steel, coke ovens	9–15	13–20	1994	1995	Jochem and Bradke, 1996; Ameling and others, 1998
Construction materials	5–10	8–15	1997	1997	
Glass production	10–15	15–25	1997	1997	ATLAS, 1997
Refineries	5– 8	7–10	1995	1997	*Refining Processes,* 1998
Basic organic chemicals	5–10		1997	1996	Patel, 1999; Brewer and Lopez, 1998
Pulp and paper		50	1996	1997	De Beer, 1998
Investment and consumer goods	10–20	15–25	1994	1995	Jochem and Bradke, 1996; Böde and others, 1999
Food	10–15		1997	1997	Jochem and Bradke, 1996
Cogeneration in industry		10–20	1997	1997	ATLAS, 1997; EC, 1999
Residential					
Existing buildings					
Boilers and burners	15–20	20–25	today's prices	1997	ETSU, 1994; Böde and others,1999
Building envelopes	8–12	10–20	today's prices	1995	Ziesing and others, 1999
New buildings		20–30	today's prices	1995	Altner, Durr, Michelson, 1995
Electric appliances	20–30	35–45	1997	1997	GEA, 1995; ECODROME, 1999; Hennicke and others, 1998; Boardman and others, 1997
Commercial, public, and agriculture					
Commercial buildings	10–20	30	8–13 cts/kWh	1995	Geiger and others, 1999
Electricity	10–25	20–37	4–10 cts/kWh	1997	ECODROME, 1998
Heat		15–25	today's prices	1998	Zeising and others, 1999
Public buildings		30–40	7–15 cts/kWh	1992	Brechbühl, 1992
Agriculture and forestry		15–20	today's prices		Neyer and Strebel, 1996
Horticulture		20–30	today's prices		Arbeitsgemeinschaft, 1992
Decentralised cogeneration		20–30	today's prices	1995	Ravel, 1994
Office equipment		40–50	1995	1995	Aebischer and others, 1996; MACEBUR, 1998; Hallenga and Kok, 1998
Transportation					
Cars	25		today's prices	1995	IPSEP, 1995
Door-to-door integration	4			1995	Zeising and others, 1999
Modal split of freight transport		3[b]		1995	
Trains and railways		20	today's prices	1999	Brunner and Gartner, 1999
Aircraft, logistics	15–20	25–30	today's prices	1998	IPCC, 1999a

a. Assumes a constant structure or use of the sector or technology considered. b. Refers to the final energy use of the entire sector.

better design and low-cost insulation techniques and window sytems (Altner and others, 1995).

The economic efficiency potential of electric appliances in 2010 is best evaluated by comparing the equipment in use with the equipment available on the market. But the market is not homogeneous: a survey of washing machines, dryers, and dishwashers available in the European Union showed minimum:maximum ratios of specific consumption between 1:2.5 for washing machines and 1:4 for condenser tumble dryers (GEA, 1995). Initial costs are sometimes higher for efficient equipment, but life-cycle costs are generally lower. In France a detailed end-use study showed that electricity savings of 40 percent can be achieved by replacing average equipment with the most efficient appliances readily available on the market (Rath and others, 1997; ECODROME, 1998). These results are confirmed by Hennicke and others (1998) and Ziesing and others (1999). Given the relatively short lives of lights and appliances, savings of 33 percent could be achieved in the United Kingdom by 2010 with the widespread adoption of better lights and appliances using known technologies (Boardman and others, 1997).

Service and public sectors. In 1990 office equipment consumed just 3–4 percent of the electricity used in Western Europe's service sector (Aebischer, Schwarz, and Spreng, 1996). But office equipment is the fastest-growing consumer of electricity. About two-thirds of this electricity is used in standby and off modes. Thus easy and cost-effective savings are possible for most equipment (Hallenga and Kok, 1998; MACEBUR, 1998). With the fast increase in the amount of office equipment and its short lives, these improvements could be realised by 2010. Hennicke and others (1998) reports that 27–35 percent of the electricity consumed by Germany's service sector could be saved for \$0.043–0.071 a kilowatt-hour.

The economic potential for reducing space and process heat demand in commercial buildings ranges from 15–25 percent (Ziesing and others, 1999; Aebischer and others,1996). The efficiency of heat generation and distribution could be improved by 10–15 percent through reinvestments in boilers, burners, and insulation and control techniques, in some cases by direct process heat generation (avoiding steam and hot water systems), and by engine-driven cogeneration.

TABLE 6.5. ECONOMIC ENERGY EFFICIENCY POTENTIALS IN NORTH AMERICA, 2010

Sector and area	Economic potential (percent)		Energy price level assumed	Base year	Source
	United States[a]	Canada			
Industry					
Iron and steel	4– 8	29	United States: scenario for price developments[b] Canada: price scenario by province[c]	United States: 1995 Canada: 1990	United States: Interlab, 1997; Brown and others, 1998; Romm, 1999 Canada: Jaccard and Willis, 1996; Bailie and others, 1998
Aluminium (primary)	2– 4				
Cement	4– 8				
Glass production	4– 8				
Refineries	4– 8	23			
Bulk chemicals	4– 9	18			
Pulp and paper	4– 8	9			
Light manufacturing	10–18				
Mining	n.a.	7			
Industrial minerals	n.a.	9			
Residential					
Lighting	53		United States: scenario for price developments Canada: price scenario	United States: 1995 Canada: 1990	United States: Interlab, 1997; Brown and others, 1998; OTA, 1992 Canada: Bailie and others, 1998
Space heating	11–25				
Space cooling	16				
Water heating	28–29				
Appliances	10–33				
Overall		13			
Commercial and public					
Space heating	48		United States: scenario for price developments Canada: price scenario	United States: 1995 Canada:1990	United States: Interlab, 1997; Brown and others, 1998 Canada: Bailie and others, 1998
Space cooling	48				
Lighting	25				
Water heating	10–20				
Refrigeration	31				
Miscellaneous	10–33				
Overall	n.a.	9			
Transportation					
Passenger cars	11–17		United States: scenario for price developments Canada: price scenario	United States: 1997 Canada: 1990	United States: Interlab, 1997; Brown and others, 1998 Canada: Bailie and others, 1998
Freight trucks	8– 9				
Railways	16–25				
Aeroplanes	6–11				
Overall	10–14	3			

a. Industrial energy efficiency potentials in the United States reflect an estimated penetration potential under different conditions based on the Interlaboratory Working Group on Energy Efficient and Low-Carbon Technologies (1997). There are no separate estimates available for the economic potential. The economic potential under business-as-usual fuel price developments is estimated at 7 percent in energy-intensive industries and 16 percent in light industries. b. The Inter-Laboratory Working Group study (1997) used price scenarios for 1997–2010 to estimate the potential for energy efficiency improvement, based on the *Annual Energy Outlook 1997* scenario (EIA, 1996). The scenario assumes a 1.2 percent annual increase in oil prices from 1997 levels. c. For comparison; in 2010 light fuel oil prices are $6–8 a gigajoule at the 1999 exchange rate (Jaccard and Willis Energy Services, 1996).

Transportation. Between 1990 and 2010 final energy use by transport may increase by 40 percent in Western Europe if no efficiency potentials are used. About 50 percent of this energy is used by passenger cars and almost 40 percent by road freight. A voluntary agreement concluded by the Association of European Car Manufacturers reflects the potential for energy-efficient car use: in 2008 new cars will be 25 percent more fuel efficient than in 1995. Using taxes and insurance to internalise the external costs of road transport, estimated at $20–70 billion, would increase efficiency by another 7–16 percent.

Relative to road transport, Western Europe's rail transport is about 3 times less energy-intensive for passengers and up to 10 times less energy-intensive for goods. With lighter trains, reduced air drag, and better drive concepts, the specific electricity consumption of rail transport could drop almost 50 percent over the next 40 years (Brunner and Gartner, 1999). A 25 percent cut in railway freight tariffs due to increased productivity and cross-border harmonisation is expected to induce a shift from road to rail, allowing a 3 percent reduction in final energy use for the transport sector as a whole. Although aeroplanes and related logistics have substantial efficiency potential (IPCC, 1999a), it is not expected to compensate for the growth in air transport mileage.

North America

North America—defined here as Canada and the United States, but not Mexico—has higher energy consumption per capita than any other region.[9] Canada and the United States share several characteristics (large size, low energy prices) but also differ substantially (climate). In both countries recent studies have assessed the potential for increased energy efficiency by 2010. In the United States the Interlaboratory Working Group on Energy-Efficient and Low-Carbon Technologies (1997) assessed the economic potential for efficiency improvement, while a recent follow-up study assesses the potential impact of policies. In Canada a study has assessed several industrial sectors in detail (Jaccard and Willis Energy Services, 1996), while others have assessed the economic potential of sets of technologies in all sectors (Bailie and others, 1998; Brown and others, 1998; Faruqui and others, 1990; OTA, 1991). Both countries are assessing policies to address climate change, and the results may vary from previous studies (table 6.5).

Between 1990 and 2010 final energy use by transport may increase by 40 percent in Western Europe, if no efficiency potentials are used.

Under the business-as-usual scenario, energy growth in the United States through 2010 would increase energy demand by 26 percent relative to 1990. Two other scenarios address, with progressively stronger measures, the adoption of energy-efficient technologies. The first, the efficiency scenario, assumes that technology-based reductions in energy and carbon emissions become cost-effective and so attractive to the marketplace. The second, the high-efficiency/low-carbon scenario, assumes that the United States makes an even greater commitment to reducing carbon emissions through federal and state programs and policies, as well as active private sector involvement. The high-efficiency/low-carbon scenario assumes that the emission charge is $25 or $50 per tonne of carbon.

Industry. Because of the complexity of industrial processes, the Interlaboratory Working Group did not model from the bottom up using explicit estimates of changes in efficiency expected from the introduction of energy-efficient technologies. Instead, the group used existing models to estimate the potential for increased general investment in industrial energy efficiency, supplemented by examples of a few technologies that have potential throughout the industrial sector (for example, advanced gas turbines and efficient motors). The models single out seven energy-intensive industries that together account for 80 percent of manufacturing energy use. Light manufacturing is considered a separate category.

Under the business-as-usual scenario, manufacturing grows 2.1 percent a year through 2010, divided between energy-intensive industries (1.3 percent a year) and non-intensive industries (2.6 percent a year). Total energy intensity is projected to decline by 1.1 percent a year (Interlaboratory Working Group, 1997).

In the efficiency scenario, industrial energy consumption drops 6.6 percent relative to the business as usual scenario. In the high-efficiency/low-carbon scenario, consumption falls 12.5 percent. Energy efficiency improvements are larger in light industry than in heavy manufacturing because there are more opportunities to adopt energy-efficient-technologies. Energy is a smaller component of overall manufacturing costs, so there is less incentive to adopt new technology than in the past. A recent bottom-up study (Worrell, Martin, and Price, 1999) of energy efficiency potential in the U.S. iron and steel industry estimates the potential contribution of nearly 50 technologies, and suggests that the potential is twice as high as indicated by the Interlaboratory Working Group study.

Bailie and others (1998) estimate at 8 percent the cost-effective potential for reducing carbon dioxide (CO_2) emissions through increased energy efficiency in Canadian industry. The authors use high discount rates to reflect the market rates of time preference.[10] Jaccard and Willis Energy Services (1996) estimate the economic and technical potential for increased energy efficiency in six major industrial sectors using the same model and a discount rate of 7 percent in assessing the macroeconomic potential (see box 6.2). They find technical potential in 2010 to vary by industry from 8 to 38 percent (relative to 1990), while economic potential varies from 7 to 29 percent. These findings are similar to those for Western Europe (see table 6.4).

Buildings. In the efficiency scenario, buildings use 36.0 exajoules of energy in 2010, compared with 38.0 exajoules in the business as usual scenario. The efficiency scenario assumes that by 2010 buildings will have achieved just over one-third of their cost-effective energy efficiency savings potential of 15 percent (Interlaboratory Working Group, 1997). Energy services cost $11 billion a year less than in the business-as-usual scenario. Costs are lower because the decrease in energy spending that results from installing more efficient technology is larger than the cost of purchasing and installing this technology in buildings. The high-efficiency/low-carbon scenario assumes that nearly two-thirds of the cost-effective energy efficiency savings are achieved by 2010. The result is a larger drop in energy use, to 33.3 exajoules—or by 13 percent relative to the business-as-usual scenario.

Bailie and others (1998) assume that energy efficiency measures are implemented in Canadian buildings. While households show moderate economic potential (13 percent), the economic potential for commercial buildings is limited (9 percent).[11] Although the technical potential is high (Bailie and others, 1998), the assumed high costs and additional office automation lead to smaller economic potentials.

Transportation. The business as usual scenario for U.S. transportation assumes that the passenger car fuel efficiency rate (in litres per 100 kilometres) will improve from 8.55 in 1997 to 7.47 in 2010. But this represents a 1.4 percent annual increase in fuel economy, an improvement that has not been seen in the past without increased fuel mileage standards or higher oil prices. The business-as-usual scenario also assumes that the fuel efficiency of light trucks will not increase. The result is an increase in transportation energy use from 26,000 petajoules in 1997 to 34,000 petajoules in 2010 despite a 10 percent improvement in overall efficiency. Under the efficiency scenario, transportation energy use is 10 percent lower in 2010. Under the high-efficiency/low-carbon scenario, it is 14 percent lower (Interlaboratory Working Group, 1997).

The high-efficiency/low-carbon scenario includes the efficiency scenario assumptions as well as major breakthroughs in fuel cells for light-duty vehicles, large gains in the energy efficiency of aircraft, and an optimistic estimate of the cost of ethanol fuel from biomass. This modelling approach is very different from that taken for buildings, because of the assumption of breakthrough technology in transportation.

Bailie and others (1998), however, estimate an extremely low economic potential for energy efficiency improvement in Canada's transportation sector.[12] The study concentrates on efficiency standards for engines but also includes fuel switching. The baseline scenario assumes large growth in transport demand, dramatically increasing energy demand in Canada between 1990 and 2010. The study finds a large technical potential for efficiency improvement, but the costs of the economic potential are prohibitive. Hence the economic potential is estimated at just 3 percent relative to 2010 baseline energy use.

Japan and Southeast Asia

The literature on energy efficiency potentials in Japan and Southeast Asia is somewhat limited (table 6.6).[13] Although the region has a relatively young capital stock, economic efficiency potentials are still quite high. This is due to intensive technological innovations and relatively high energy prices (Rumsey and Flanagan, 1995a).

Between 1975 and 1995 primary energy demand more than quadrupled, shifting the centre of the energy market from the Atlantic Basin to the Pacific Basin (Fesharaki, 1998). Hence energy efficiency is a paramount policy objective. The Asia Least Cost Greenhouse Gas Abatement Strategy (ADB, GEF, and UNDP, 1998) cites cumulative potentials for 2010 and 2020.

Industry. Goto (1996) estimates industrial energy efficiency improvements through 2010 for several energy-intensive branches in Japan (see table 6.6). The energy savings for iron and steel range from 10–12 percent, for chemicals from 5–10 percent, for cement production from 2–8 percent, and for pulp and paper from 6–18 percent (box 6.4). For Southeast Asia, ADB, GEF, and UNDP (1998), IIEC (1995), Adi (1999), Ishiguro and Akiyama (1995), and the Viet Namese government find that similar savings are possible in 2010 and 2020.

Residential, commercial, and public sectors. The energy savings potential of residential and commercial uses could be untapped with various demand-side management programmes for air conditioning, refrigeration, lighting, and cooling. Some 300–450 petajoules a year could be gained in Japan's residential sector by insulating existing buildings within their reinvestment cycle. IIEC (1995) reports savings of 20–60 percent for electric appliances.

TABLE 6.6. ECONOMIC ENERGY EFFICIENCY POTENTIALS IN JAPAN AND SOUTHEAST ASIA, 2010 AND 2020

Sector and area	Economic potential (percent or petajoules a year)[a]		Energy price level assumed (U.S. cents per kilowatt-hour)	If percent, base year	Source
	Japan 2010	Southeast Asia 2020			
Industry					Japan: Goto, 1996; JISF, 1993 Southeast Asia: Ishiguro and Akiyama, 1995; ALGAS, 1998, IIEC, 1995; Adi 1999; Government of Viet Nam; Nguyen Thuong, 1998; Aim Project Team, 1994
Iron and steel	10–12%		0.2	1990–95	
Cement	2–8%		2–20	1990–95	
Chemicals	5–10%		0.4–7.8	1990–95	
Pulp and paper	6–18%		1.5– 3.3	1990–95	
Electric motors		20%	1998 prices	1995	
Total industry		**2,017 PJ**	**1998 prices**	**1998**	
Residential					Kaya and others, 1991; IIEC, 1995; ALGAS, 1998; Wanwacharakul, 1993
Existing buildings					
50-100 millimetre insulation	290–450 PJ		2.0–8.5	1995	
Electric appliances	20–60%	20–60%			
Illumination	20–75%	20–60%			
Commercial and public sectors					IIEC, 1995; ALGAS, 1999
Buildings					
50-100 millimetre insulation	240–280 PJ	293 PJ	2–5	1991,92	
Transportation		**2,275 PJ**		**1992**	IIEC, 1995 Japan: Goto, 1996; Aim Project Team, 1994
Compact cars	1.8%		0.044	1990	
Buses	0.2%		0.196	1990	
Trucks	2.8%		0	1990	
Compact cargo vehicles	13.7%		0	1990	
Within cities					
Vehicles	7%		0.01–0.06	1990	
Buses, trucks cargo vehicles	14%		0.01–0.06	1990	
Passenger cars	0.3%		0.06	1990	

a. Assuming constant structure or use of the sector or technology considered.

BOX 6.4. JAPANESE COMPANIES GO AFTER OPPORTUNITIES

Hitachi city district heating system. Energy displacement between industry and buildings entails the use of residual heat from a cement factory for district heating and cooling in Hitachi city covering a total area of 12.5 hectares. Some 107,000 square metres of floor area will be covered by the district heating system, with a maximum supply capacity of 8.93 gigawatts of heat and 11.9 gigawatts of cooling. When the system produces a surplus of heat, the excess heat is used for electricity production with a 373 kilowatt-hour generator (Kashiwagi, 1994).

Iron and steel. Efficient ignition of a sintering furnace for crude steel production is possible through installed segregation equipment, slit burners, and changes in waste heat recovery—for savings of 56.5 gigajoules a year. Ignition fuel was reduced by 70 percent with a payback period of 1.6 years at 1986 prices (CADDET, 1997).

Cogeneration. The Jujo Kimberly K.K cogeneration power plant for a paper mill uses an aeroengine-driven gas turbine with an output of 7,600 kilowatts of electricity and 20 tonnes per hour of steam, meeting 70 percent of the mill's electricity requirements. The system attains an overall efficiency of 81 percent, with a payback of four years. Energy costs were cut 30 percent, and labour costs 20 percent. The space saves confers an additional economic benefit.

In the commercial and public sectors the same efficiency technology would save 240–280 petajoules a year. Mungwitikul and Mohanty (1997) report electricity savings of 25 percent for office equipment at no additional cost in Thailand.

Transportation. In 1980–95 transport was the largest consumer of energy in Japan and Southeast Asia, with annual growth of 8.8 percent (excluding Viet Nam). Transport energy demand is still increasing because larger vehicles are becoming more popular, while the share of small vehicles in new car sales fell to 60 percent in 1996. Japanese government policy is now aiming to introduce the 'top runner method', setting efficiency standards above the performance standards currently achievable in order to raise vehicle fuel efficiencies. These measures include subsidies for hybrid vehicles, which double fuel efficiencies. Smaller cars are expected to reduce their fuel consumption to 3.0–3.6 litres per 100 kilometres, and one car manufacturer plans to increase efficiency by 25 percent between 1995 and 2005.

Energy policy also attempts to improve the energy efficiency of trains, ships, and planes, upgrading distribution efficiency by promoting railroad transportation, coastal shipping, and public transport. A study on an electric mass transit project under construction in Thailand identified potential savings of 28 petajoules a year. The savings would come from switching to diesel fuel in city buses. The introduction of fuel cells in road vehicles will further improve efficiency after 2010.

Eastern Europe

Economic restructuring is playing a decisive role for the energy system and its efficiency path in Eastern Europe, because the drivers of economic policy are now totally different from those under central planning.[14] Under communist rule a standing ambition for expansion led to a very old capital stock with low energy efficiency for basic industries, buildings, and the energy industry itself. Because the region started the transition from an extremely weak social and financial position, the economic crisis—an unavoidable element of large-scale restructuring—influences voters (Levine and others, 1991).

As a result governments (who wish to remain in power) are often reluctant to take the restrictive steps needed for economic restructuring in general and energy pricing in particular. Countries starting from a better position (Czech Republic, Hungary, Poland, Slovakia, Slovenia) can take the painful steps earlier. Because statistical systems and aggregation practices differ considerably among transition economies and future developments are uncertain, the data on economic efficiency energy potential in table 6.7 should be viewed only as cautious estimates. The data may be subject to major changes when more empirical data become available.

Industry. Specific energy consumption and related efficiency

TABLE 6.7. ECONOMIC ENERGY EFFICIENCY POTENTIALS IN EASTERN EUROPE, 2010

Sector and area	Economic potential (percent)	Energy price level assumed	Base year	Source
Industry				
Pig iron	3	EU, 1995		Ministry of Industry, Poland, 1990
Electric steel	10	EU, 1995		
Hot rolled products	32	EU, 1995		
Ferrous metallurgy	24	EU, 1995		
Electrolytic copper	15	EU, 1995		
Aluminium	24	EU, 1995		National Energy Agency, Bulgaria, 1998
Non-ferrous metals	4	EU, 1995		
Chemical products	31	EU, 1995	1995	
Synthetic fibres	12	EU, 1995		
Building materials	48	EU, 1995		
Cement dry	16	EU, 1995		
Leather, footwear	4	EU, 1995	1995	
Timber, wood industry	5	EU, 1995	1995	
Food industry	23	EU, 1995	1995	
Machine manufacturing	22	EU, 1995	1995	
Construction industry	24	EU, 1995	1995	
Residential				
Existing stock	25	EU, 1995	1995	IEA, 1999
New buildings	30	EU, 1995	1995	
Electric appliances	25	EU, 1995	1995	
Commercial/public				
Heating	25		1995	IEA, 1999
Office equipment	20		1995	
Lighting	40	EU, 1995	1995	
Agriculture				
Heating, drying	22	EU, 1995	1995	IEA, 1999
Electricity	15	EU, 1995	1995	
Transportation				
Cars	20	EU, 1995	1995	IEA, 1999
Public transportation, cities	15	EU, 1995	1995	
Railways	25	EU, 1995	1995	
Air transport	22	EU, 1995	1995	

potentials are related to physical production in energy-intensive industries. The economic potential of other sectors ranges from 4 percent (leather) to 40 percent (building materials) by 2010 (see table 6.7). Available data are from climatically and economically different countries (from Bulgaria to Poland) but most of the figures are similar—reflecting a shared history of Soviet technology and standards.

Residential. Individual heat metering in multifamily houses in Eastern Europe represents an energy efficiency potential of at least 15–20 percent. In panel-built housing estates, individual metering of domestic warm water consumption has already resulted in savings of up to 40 percent where it has been introduced. A programme to improve thermal insulation in these buildings began in the mid-1990s with central support. Thus a 20–30 percent reduction of the heat demand in these buildings can be achieved in the next 10 years.

For 2020 and beyond, specific energy and material demands are expected to be close to the EU average. Economic and technology development in Eastern Europe will likely be carried out through the expansion of multinational companies, integration with the European Union, and globalisation. As a consequence, by 2020 technologies will be in place that are technically and economically acceptable and comparable to EU standards. Exceptions will be some parts of the non-refurbished building stock.

Commercial and public sectors. Improved boilers and heating systems, insulation, high-efficiency window systems, and new lighting systems will contribute to substantial savings in the commercial and public sectors.

Transportation. Although specific energy consumption will likely fall by at least 1 percent a year, the final energy consumed by road transportation will substantially increase due to motorization in Eastern Europe.

Russia and other members of the Commonwealth of Independent States

Members of the Commonwealth of Independent States face very different climates, domestic energy resources, and levels of industrialisation and motorisation.[15] The last extensive studies of economic energy efficiency potentials for the former Soviet Union were performed in the early 1990s (WBNSS, 1999). About 120 technologies and energy-saving measures with potential savings greater than 5.8 petajoules a year were considered, covering all the sectors and assuming the replacement of technology and equipment in use at that time with best-practice, world-class technology (CENEf, 1993). Potential savings were estimated at 21,690 petajoules a year, about 77 percent of

TABLE 6.8. ECONOMIC ENERGY EFFICIENCY POTENTIALS IN RUSSIA AND UKRAINE, 2010

Sector and technological area	Economic potential (percent or petajoules a year)		Energy price level assumed	If percent, base year		Source
	Russia	Ukraine		Russia	Ukraine	
Industry	**3,370–4,980 PJ**	**1,430–2,485 PJ**	1990s price levels of Western Europe	1995	1990	Russia: Federal Ministry of Fuel and Energy, 1998 Ukraine: ARENA-ECO, 1997; Vakulko/Zlobin, 1997
General	1,524–2,198 PJ			1995		
Metallurgy	733–1,026 PJ	284– 361 PJ		1995	1990	
Iron and steel, coke ovens	132– 161 PJ			1995		
Construction materials	440 PJ					
Cement	176 PJ			1995		
Refineries	176– 205 PJ	73– 138 PJ[a]		1995	1990	
Basic organic chemicals	176– 322 PJ			1995		
Pulp and paper	176– 322 PJ			1995		
Investment goods industry	322– 469 PJ	247– 249 PJ		1995	1990	
Electricity savings	More than 30%			1997		
Food industries		114– 205 PJ				
Commercial and public sectors and agriculture			1995 price levels of European Union			Bashmakov, Gritsevich, and Sorokina, 1996; ARENA-ECO, 1997; Lapir, 1997
Commercial buildings						
Agriculture	791– 879 PJ	91– 138 PJ		1995	1990	
Horticulture	Up to 3 times			1997		
Residential	**1,905–2,198 PJ**	**475–570 PJ[b]**	1995 price levels of European Union	1995	1990	Bashmakov, Gritsevich, and Sorokina, 1996; ARENA-ECO, 1997
Automated boilers	20–40%			1995		
Existing building stock	20–30%			1995		
New buildings	381– 431 PJ			1995		
Hot water supply	197– 276 PJ			1995		
Transportation	**967–1,172 PJ**	**290–293 PJ**	1995 price levels of European Union	1995	1990	Russia: SNAP, 1999; Russian Federation, Ministry of Transport, 1995
Trains	10–15%			1997		

a. Refineries and chemicals. b. Residential and commercial sectors.

BOX 6.5. MARKET FORCES DRIVE MORE ENERGY-EFFICIENT INDUSTRY IN THE COMMONWEALTH OF INDEPENDENT STATES

Automated controls introduced in the processing of petrochemicals reduced electricity consumption per unit of output by 40–65 percent at the Kirishinefteorgsyntez plant in Leningrad oblast. Narrower fluctuations in technological parameters also increased the lives of electric motors, valves, and transmitters (Goushin and Stavinski, 1998).

At one of Russia's largest ferrous metallurgy plants, Magnitogorski, the energy management department developed and implemented a programme for energy saving and efficiency that took into account the plant's new market environment. The programme focuses on making better use of internal energy resources. Steam is now used for electric power cogeneration (26 megawatts), and coke gas is used as a fuel at boilers-utilisers and in the drying of containers for transporting iron, replacing 19,000 cubic metres of natural gas (Nikiforov, 1998).

which was considered economical by 2005.

In 1996 Russia and Ukraine—the two largest members of the Commonwealth of Independent States—used 83 percent of the region's primary energy. The most recent estimate of Russia's energy efficiency potential was developed in 1997 (Russian Federation Ministry of Fuel and Energy, 1998). It projects savings of 13,000–15,500 petajoules by 2010; 80 percent of these savings are expected in the end-use sector. The most comprehensive recent evaluation of technological and economic potentials for energy efficiency in Ukraine was undertaken by the Agency for Rational Energy Use and Ecology (ARENA-ECO, 1997).

Industry. The economic efficiency potential of industry in 2010 is about 4,000 petajoules a year (table 6.8). This is equal to about 30 percent of the economic efficiency potential of the entire economy, or more than 30 percent of the projected energy demand for 2010. In ferrous metallurgy, replacing open-heart furnaces with oxygen converters and electric steel furnaces could save 73–88 petajoules a year (box 6.5). Introducing continuous casting on greater scale could save 59–70 petajoules a year. Recycling an additional 10 million tonnes of ferrous scrap would save 290 petajoules a year.

In primary aluminium production it is realistic to cut the use of electric power to 13,200 kilowatt-hours per tonne by using electrolysers of greater capacity and introducing automated control of technological parameters. In the production of building materials the transfer of cement clinker production to dry process in the production of bricks and lime and other related measures may cut energy use by 400 petajoules a year. In the chemical industry, replacing obsolete with modern technology in the production of ammonia, olefines, aromates, alcohols, and the like will not only reduce energy intensity to levels comparable to the best world examples (around 200 petajoules in 2010), it will also improve the product mix.

According to Vakulko and Zlobin (1997), the main directions for rational use of electricity in industrial facilities are: installing electricity metering and control devices, practising power compensation, determining the optimal number of working transformers, and making efficient use of lighting and lighting devices, high-efficiency electric drives, electrothermal devices, welding transformers and units, and converters. Ukraine's energy efficiency potential in industry is similar once adjusted for the smaller country, but are still about 2,000 petajoules a year by 2010 (see table 6.8).

Residential. Better building insulation will reduce heat losses. Overall, by 2010 Russia could save at least 2,000 petajoules a year in its residential sector. Ukraine could save 500 petajoules a year (see table 6.8). Typical for Russian households, a 250–360-litre refrigerator consumes 500–600 kilowatt-hours a year. According to Bashmakov, Gritsevich, and Sorokina (1996), more energy-efficient refrigerators could save up to 175 petajoules a year by 2010. The efficiency measures in this sector and the commercial sector are very similar to those in Russia (installing new metering and control devices, improving insulation of buildings and heating systems).

Transportation. Russia's Ministry of Transport has adopted several programmes to make the transportation system more efficient, safe, and comfortable (SNAP, 1999). In 1995 the ministry introduced a programme aimed at introducing energy-saving vehicles, optimising the structure of the vehicle stock, developing energy-efficient engines, and introducing energy-saving fuels and lubricants (Russian Federation Ministry of Transport 1995). Among other measures, the programme is expected to increase of the share of diesel-fuelled trucks and buses and modernise aeroplanes and helicopters.

Though there is great potential for economic energy savings, these savings will be difficult to achieve. Russia and Ukraine cannot provide the necessary financial support to industry and municipalities. Current investments in energy-saving measures are so low that less than 10 percent of economic energy saving potential is being reached in the Commonwealth of Independent States (Bashmakov, Gritsevich, and Sorokina, 1996). But this is likely to change with the economic recovery of Russia and Ukraine over the next 10 years.

India

With more than 1 billion inhabitants, India is one of the world's biggest emerging economies.[16] In the 50 years since independence the use of commercial energy has increased by ten times, and in 1996/97 was 10,300 petajoules (GOI, Ninth Plan Document, 1996). But per capita energy consumption is only about 15 gigajoules a year (including non-commercial energy)—far below the world average of 65 gigajoules. Given the ever-widening gap between energy supply and demand in India, and the resource constraint impeding large-scale energy generation at source, efficient energy use is an extremely important, cost-effective option. Commercial energy use is dominated by industry (51 percent), followed by transportation (22 percent), households (12 percent), agriculture (9 percent), and other sectors including basic petrochemical products (6 percent).

Industry. Indian industry is highly energy-intensive, with energy efficiency well below that of industrialised countries (see table 6.3). Efforts to promote energy efficiency in such industries could substantially reduce operating costs. About 65–70 percent of industrial energy consumption is accounted for by seven sectors—fertiliser, cement, pulp and paper, textiles, iron and steel, aluminium, and refineries.

TABLE 6.9. ECONOMIC ENERGY EFFICIENCY POTENTIALS IN INDIA, 2010

Sector and technological area	Economic potential (percent or units of energy a year)	Energy price level assumed	If percent, base year	Source
Industry				
Fertiliser	12.6 gigajoules per tonne of NH_3	Today's price		TERI and FAI, 1995
Cement	17%	Today's price	1992	TIFAC, 1992
Electrical	17%			
Thermal	27%			
Pulp and paper	20–25%	Today's price	1994	CII, 1994
Textiles	23%	Today's price	1998	TERI, 1999
Iron and steel	15%	Today's price	1998	TERI, 1996a
Aluminium	15–20%	Today's price	1996	TERI, 1996b
Refineries	8–10%	Today's price	1996	Raghuraman, 1989
Brick-making	15–40%	Today's price	1989	TERI, 1997b
Foundries	30–50%	Today's price	1997	TERI, 1998
Industrial cogeneration	3,500 megawatts (sugar)	Today's price	1997	TERI, 1994
Residential				
Lighting	10–70%	Today's price	1996	TERI, 1997c
Refrigerator	25%	Today's price	1996	TERI, 1997c
Air conditioning	10%	Today's price	1996	TERI, 1997c
Agriculture				
Pump sets	25–55%	Today's price	1995	Kuldip and others, 1995
Transportation				
Two- and three-wheelers	25%	Today's price	1995	IIP, 1995
Cars	7.5–10%	Today's price	1992	TERI, 1992
Trains (diesel)	5–10%	Today's price	1997	TERI, 1997c
Trains (electric)	5–10%	Today's price	1997	TERI, 1997c

The other areas considered for this report are brick-making, foundries, and industrial cogeneration. Potential efficiency improvements are the result of a bundle of feasible and economic energy-saving options, identified through energy and technology audits (table 6.9, box 6.6).

Residential. Energy consumption in India's residential sector varies widely across low-, medium-, and high-income classes in rural and urban areas. Household demand for electricity will likely expand rapidly as urbanisation continues and the availability of consumer durables expands with increasing income. About 40 percent of the electricity used by the sector goes to meet lighting demand, followed by 31 percent for fans and 28 percent for appliances (refrigerators, air conditioners, televisions). The economic potential of efficiency improvements was estimated for lighting (up to 70 percent), refrigerators (25 percent), and air conditioners (10 percent; see table 6.9).

Agriculture. The main areas for conserving energy in agriculture are diesel-fuelled and electric pumps, 16 million of which were in operation in 1991/92. The estimated savings potential of 25–55 percent involves avoiding such common drawbacks as improper selection of pumps and prime movers, improper installation, poor pump characteristics, high friction losses in the valves and the piping system, air inflow in the suction pipe, and improper maintenance and servicing.

Transportation. Transportation accounts for almost half of India's oil product consumption, in the form of high-speed diesel and gasoline (TERI, 1999). Two major structural aspects of transportation are related to energy efficiency. First, the rail-dominant economy of the 1950s gave way to the road-dominant economy of the 1990s, reaching 81 percent of the sector's energy consumption (TERI, 1997c). Second, inadequate public transport systems and increasing incomes have led to a rapid increase in personalised modes of transport and intermediate public transport, some of which are extremely energy-inefficient.

A large number of two-stroke-engine two-wheelers are used as

BOX 6.6. MORE ENERGY-EFFICIENT FOUNDRIES IN INDIA

Until recently most of India's 6,000 small foundries had conventional cupolas (melting furnaces) with low energy efficiencies and high emissions. In 1998 a new divided-blast cupola and pollution control system were commissioned and fine-tuned. Once various control parameters were optimised, the demonstration cupola was far more energy efficient, with coke savings ranging from 33–65 percent relative to average small-scale foundries in India. Emissions of total suspended particulates are below the most stringent emission norm prevailing in India. In addition, the new cupola has a much reduced oxidation loss for silicon and manganese. This success story outlines an appropriate strategy for small-scale foundries to upgrade to an energy-efficient and environmentally cleaner option. This strategy can be adapted not only to other industry clusters in India, but also to units operating under similar conditions in other countries.

Source: TERI, 1998.

personal vehicles. (In 1996 the number of registered two-wheelers was 23.1 million.) Efficiency improvements of 25 percent are possible for two-stroke engines (two- and three-wheelers). The stringent emission standards proposed for two- and three-wheelers will force manufacturers to switch to four-stroke engines. Efficiency improvements for cars and buses are expected to come primarily from switching from gasoline and diesel to compressed natural gas (TERI, 1992).

The importance of research and development for increasing energy efficiency is still underestimated in India. Spending on research and development increased from 0.35 percent of GNP in 1970 to 0.81 percent in 1994. But this share is still just one-third of the ratio in industrialised countries. Tackling the complex technological problems of the energy sector, particularly end-use efficiencies, will require research and development on a steadily increasing scale.

China

Like India, China is one of the world's main emerging economies, with a population of more than 1.2 billion.[17] In 1996 China's primary energy demand was 44,000 petajoules, or 36 gigajoules per capita. Substantial energy efficiency gains could be realised through intensive investments in the country's productive sectors.

Industry. In 1995 steel and iron industry consumed 3,740 petajoules, accounting for 13 percent of China's final energy use with a performance of 46 percent energy efficiency. Energy consumption per tonne of steel will likely drop from 44 gigajoules in 1995 to 35 gigajoules in 2010, which is a little higher than the level in industrialised countries in the 1970s (table 6.10). The potential efficiency savings in some other energy-intensive branches are higher—construction materials could achieve 20 percent and chemicals up to 30 percent, with particular savings in basic chemicals such as ammonia, sulphate, soda, carbide, and olefine production.

Residential. Since the 1980s domestic energy consumption has increased because of higher living standards and expanded living space. Measures such as preventing heat losses, improving electric appliance efficiency, replacing incandescent lamps with fluorescent lamps, improving stoves and boilers, and using cogeneration will enhance energy efficiency in this sector. In 1995 the average efficiency of China's energy use—as defined by the relationship between useful energy and final energy—was 45 percent in urban areas and 25 percent in rural areas, indicating considerable potential for improvement. By 2010 energy efficiency is expected to reach 50 percent in urban areas and 45 percent in rural areas, close to

TABLE 6.10. ECONOMIC ENERGY EFFICIENCY POTENTIALS IN CHINA, 2010

Sector and area	Economic potential (percent)	Energy price level assumed	Base year	Reference
Industry				
Iron and steel	15-25	Today's price	1995	Hu, 1997
Cement	10-20	Today's price	1995	Hu, 1997
Foundries	8-14	Today's price	1995	Hu, 1997
Pulp and paper	20-40	Today's price	1995	Hu and Jiang, 1997
Textiles	15-28	Today's price	1995	Hu, 1997
Fertiliser	10-20	Today's price	1995	Hu and Jiang, 1997
Aluminium	20	Today's price	1995	Hu and Jiang, 1997
Brick kilns	32	Today's price	1995	Hu and Jiang, 1997
Refineries	5-10	Today's price	1995	Hu and Jiang, 1997
Ethylene	10-30	Today's price	1995	Hu and Jiang, 1997
Calcium carbide	10-22	Today's price	1995	Hu and Jiang, 1997
Sulphate	14-25	Today's price	1995	CIECC, 1997
Caustic soda	10-30	Today's price	1995	CIECC, 1997
Household				
Lighting	10-40	Today's price	1995	CIECC, 1997
Refrigerator	10-15	Today's price	1995	CIECC, 1997
Air conditioner	15	Today's price	1995	CIECC, 1997
Washing machine	15	Today's price	1995	CIECC, 1997
Cooking utensils	20-40	Today's price	1995	CIECC, 1997
Heating equipment	10-30	Today's price	1995	CIECC, 1997
Agriculture				
Motors	10-30	Today's price	1995	CIECC, 1997
Pump sets	20-50	Today's price	1995	CIECC, 1997
Transportation				
Train (diesel)	5-15	Today's price	1995	Hu, 1997
Train (electric)	8-14	Today's price	1995	Hu, 1997
Cars	10-15	Today's price	1995	Hu, 1997
Vessels	10	Today's price	1995	Hu, 1997

levels in industrialised countries in the early 1990s (box 6.7). This means savings of 10–15 percent in urban areas and 80 percent in rural areas. These gains are important because the drivers for energy services will be increasing by 5–18 percent a year.

Low-energy houses need only 10–30 percent of the heat per square metre that is used in the average residential building in West Germany.

Other sectors. In 1995 other final energy users in the service sector had an average end-use efficiency of about 40 percent. By 2010 technological progress and technical measures are expected to increase the efficiency level by 5–10 percentage points over 1995, reaching the level of industrialised countries in the early 1990s.

Transportation. Transportation is a large and fast-growing energy-consuming sector, especially for petroleum products (2,640 petajoules in 1995, including public transport). By 2010 energy consumption will almost double, with oil products accounting for 87 percent of transport energy consumption. Relative to other sectors, transportation has a low end-use efficiency of around 30 percent. The main technical measures for increasing efficiency are similar to those elsewhere: increase the share of diesel vehicles, rationalise the weight of cars, speed up road construction and improve its quality; increase the share of electric engines and internal combustion engines on trains, and optimise engines. Better-designed propellers on ships could save 5 percent on ships' fuel consumption. Optimal ship shape energy-saving technology will save 4–10 percent of fuel, and the use of tidal energy another 3–5 percent.

Latin America

Primary energy demand in Latin America grew 2.3 percent a year over the past 20 years, reaching 18,130 petajoules in 1996.[18] The region also contains several emerging economies that are increasing world energy demand. In 1997 Argentina, Brazil, Mexico, and Venezuela used 85 percent of the region's primary energy (EIA, 1999b).

Industry. Four sectors (cement, iron and steel, chemicals, food and beverages) consume 60 percent of industrial energy in Latin America. Iron and steel alone account for 23 percent of industrial energy. Better management of blast furnaces, the injection of gases, and improved processes could reduce energy demand by 10–28 percent (Cavaliero, 1998). Machado and Shaeffer (1998) estimate potential electricity savings of 23 percent in Brazil's iron and steel industry and 11–38 percent in its cement industry (table 6.11). The food and beverage industry and chemical industry have similar efficiency potential (Argentina Secretaria de Energía, 1997; Jannuzzi, 1998).

In Brazil's industrial sector, electrical motors consume 51 percent of electricity, electrochemical processes 21 percent, electrothermal processes 20 percent, refrigeration 6 percent, and lighting 2 percent (Geller and others, 1997 and 1998). In Argentina nearly 75 percent of industrial electricity is used in motors (Dutt and Tanides, 1994) and in Chile it is 85 percent (Valdes-Arrieta, 1993). The Brazilian Electricity Conservation Agency estimates that savings of 8–15 percent are achievable in Brazilian industry based on cost-effective measures such as replacing oversized motors, improving transmission systems, replacing overloaded internal lines and transformers, correcting low power factors, and reducing excessive peak loads (box 6.8). Additional savings of 7–15 percent could be achieved by using efficient motors and variable speed drives; improving electrical furnaces, boilers, and electrolytic process efficiencies; and disseminating cogeneration in industry (Geller and others, 1998; Soares and Tabosa, 1996). Recycling the heat surplus or installing more efficient equipment could reduce by 10 percent the amount of electricity used in electric ovens. Similar savings for Argentina have been estimated by Dutt and Tanides (1994) and Argentina Secretaria de Energía (1997).

The significant potential of combined heat and power is under-exploited in most Latin American countries. The potential is great in sectors such as paper and pulp, chemicals, and the alcohol-sugar industry, because they produce industrial residues that can be used to generate a surplus of electricity, which can then be sold to the common grid. Legislation establishing independent power producers is in place, but there are still problems in regulating buy-back rates, maintenance power, and wheeling between industry and electric utilities.

Residential. Annual energy use for cooking is estimated at 5.2 gigajoules per capita, nearly half of which is from firewood (data cover only Argentina, Brazil, Mexico, and Venezuela). The use of biomass (firewood and charcoal) is declining, however, and the use of liquefied petroleum gas and natural gas is on the rise. Because these fuels are more efficient, per capita energy consumption will be 20 percent lower by 2020. During 1990–95 per capita residential electricity use increased by 4–5 percent a year in Brazil and Mexico. Specific savings in electricity use by appliances range from 20–40 percent over the next 10–20 years for several Latin American countries (see table 6.11).

Commercial and public sectors. More efficient energy use in the commercial and public sectors can be achieved by introducing better

BOX 6.7. GREEN LIGHT PROGRAMME OF CHINA

China's Green Light Programme is an energy conservation project supported by UNDP and organised and carried out by the State Economic and Trade Commission of China. The programme is designed to increase the use of lighting systems that are highly efficient, long-lasting, safe, and stable. The goal is to save electricity, reduce environmental pollution from power generation, and improve the quality of working and living. The programme has had several achievements:

- **Electricity savings.** During 1995–2000, 300 million compact fluorescent lamps, thin-tube fluorescent lamps, and other high-efficiency illumination products will save 22 terawatt-hours of electricity (as final energy).
- **Reduced emissions.** By 2000 sulphur dioxide emissions will be reduced by 200,000 tonnes and carbon dioxide emissions by 7.4 million tonnes.
- **Establishing the market.** By creating market-driven demand for high-efficiency lighting products, China will minimise spending for the associated gains. Close attention has been given to upgrading energy-efficient products by improving quality standards and certification.

TABLE 6.11. ECONOMIC ENERGY EFFICIENCY POTENTIALS IN LATIN AMERICA, 2010 AND 2020						
Sector and area	**Economic potential (percent)**		**Country/ region**	**Energy price level assumed**	**Base year**	**Source**
	2010	**2020**				
Industry Electric motors and drives Refrigeration Process heat	15–30[a,d] 27–42[b] 10–20	30 15–30[c] 21–44	Mexico Argentina Brazil Chile	0.06–0.09 (elect)[d] 0.01–0.02 (fuels)[b]	1996 1997 1997 1994	México Secretaria de Energía, 1997; Argentina Secretaria de Energía, 1997; EIA, 1999a; Geller and others 1998; IIEC, 1995; Sheinbaum and Rodriguez, 1997
Iron and steel		23[b] (elect) 28[b] (coke) 15[a] 10[d]	Brazil Argentina Chile		1998 1994	Machado and Shaeffer, 1998; Cavaliero 1998; Argentina Secretaria de Energía, 1997; EIA, 1999a; IIEC, 1995
Cement		11–38[b] (elect)	Brazil		1998	Machado and Shaeffer, 1998; Sheinbaum and Ozawa, 1998
Food and beverage		20[b] 30[a] 6[d] (elect)	Brazil Argentina Chile		1998 1998 1994	Jannuzzi, 1998; Argentina Secretaria de Energía, 1997; EIA, 1999a; IIEC, 1995
Residential		**20-40 (elect)**	Mexico, Argentina Brazil		1996 1997 1998	México Secretaria de Energía, 1997; Argentina Secretaria de Energía, 1997; EIA, 1999a; Machado and Shaeffer, 1998; Friedmann, 1994
Cooking		24	Latin America		1997	Author's estimate
Electrical appliances	20–25	20–40	Mexico Brazil		1996 1997	México Secretaria de Energía, 1997; Geller and others 1998
Lighting	30–80		Brazil Argentina	0.03–0.13 (fuels and electricity)[b]	1997 1991	Jannuzzi, 1998; Argentina Secretaria de Energía, 1997; EIA, 1999a; Blanc and de Buen, 1994
Refrigeration		35–50	Brazil Argentina Mexico		1998 1996	Machado and Shaeffer, 1998; México Secretaria de Energía, 1997
Commercial and public	**20–40 (elect.)**		Mexico Argentina Chile		1996 1997	México Secretaria de Energía, 1997; Argentina Secretaria de Energía, 1997; EIA, 1999a; IIEC, 1995
Shopping centres		13–38 (elect.)	Brazil		1998	Machado and Shaeffer, 1998
Hotels		12–23	Brazil		1998	Machado and Shaeffer, 1998
Lighting	40		Mexico Brazil		1996 1990	México Secretaria de Energía, 1997; Jannuzzi and others, 1991; Bandala, 1995
Public lighting	21-44[a] 37[d]		Argentina Chile	0.05[d]	1991	Argentina Secretaria de Energía, 1997; EIA, 1999a; IIEC, 1995
Transportation	**25**		Argentina		1998	

Note: Data for Argentina refer to the estimated technical potential. Data for Chile are for 2020; for Brazil, 2020 or 2010, as indicated; for Argentina, 2010 or 1998, as indicated; and for Mexico, 2006. a. Argentina. b. Brazil. c. Mexico. d. Chile.

boilers and maintenance practices as well as small cogeneration. Mexico is implementing building standards, which will accelerate improvements in energy use (Huang and others, 1998). For lighting, air conditioning, and refrigeration, the main electrical end uses, substantial efficiency improvements are possible for most Latin American countries (see table 6.11).

Transportation. About two-thirds of Latin America's transport energy demand is concentrated in Brazil and Mexico, where road transport accounts for 90 percent of the sector's energy consumption. Past improvements in the average specific energy consumption of passenger cars in Mexico (from 491 megajoules per 100 kilometres in 1975 to 423 megajoules in 1990) will likely continue at a similar

BOX 6.8. EFFORTS TO PROMOTE ENERGY USE BY THE BRAZILIAN ELECTRICITY CONSERVATION AGENCY

In the mid-1980s the Brazilian government established PROCEL, a national electricity conservation agency. The agency is responsible for funding and coordinating energy efficiency projects carried out by state and local utilities, state agencies, private companies, universities, and research institutes. It is also responsible for evaluating efficiency programs carried out by privatised utilities. PROCEL also helps utilities obtain low-interest financing for major energy efficiency projects. In 1998 PROCEL's core budget for grants, staff, and consultants was about $20 million, with about $140 million a year going towards project financing.

PROCEL estimates that its activities saved 5.3 terawatt-hours of electricity in 1998, equivalent to 1.8 percent of Brazil's electricity use. In addition, PROCEL took credit for 1.4 terawatt-hours of additional power production due to power plant improvements that year. The electricity savings and additional generation enabled utilities to avoid constructing about 1,560 megawatts of new capacity, meaning approximately $3.1 billion of avoided investments in new power plants and transmission and distribution facilities. The overall benefit-cost ratio for the utility sector was 12:1. About 33 percent of the savings in 1998 came from efficiency improvements in refrigerators, freezers, and air conditioners, 31 percent from more efficient lighting, 13 percent from installation of meters, 11 percent from motor projects, 8 percent from industrial programs, and 4 percent from other activities (Geller and others, 1998).

rate (Sheinbaum, Meyers, and Sathaye, 1994). Mexico's freight transport has seen efficiency improve from 2.47 megajoules per ton-kilometre in 1975 to 1.8 megajoules per ton-kilometre in 1988. Subway systems have not grown at the same rate as passenger demand for travel in Latin America's major cities, the exception being Curitiba, Brazil. In Argentina the Energy Secretariat estimates that 12 petajoules of fuel can be saved each year in passenger and freight transportation (about 25 percent of the transport sector's energy use in 1995; Argentina Secretaria de Energía, 1998f).

Africa

Africa has great potential for energy efficiency savings in industry, households, and transportation, which together account for more than 80 percent of the continent's energy consumption (21 gigajoules per capita in 1996).[19] When assessing the economic efficiency potentials in table 6.12, however, one has to keep in mind the enormous differences in development in Africa and the fact that the literature on this subject is scarce and often dated. South Africa and most North African countries are at more advanced stages of industrialisation and motorisation than the rest of the continent.

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			
Iron and steel	7.2	Kenya			Nyoike, 1993
Cement	11.3	Kenya			Nyoike, 1993
	15.4	Ghana		1988	Opam, 1992
	9.8	Kenya			Nyoike, 1993
Aluminium (sec.)	44.8	Kenya			Nyoike, 1993
Refineries	6.3	Kenya			Nyoike, 1993
Inorganic chemicals	19.0	Kenya			Nyoike, 1993
Consumer goods	25	Kenya			Nyoike, 1993
Food	16–24	Mozambique		1993	SADC, 1997
	1–30	Ghana		1988	Opam, 1992
Cogeneration	600 MW	Egypt		1998	Alnakeeb, 1998
Residential					
Electric appliances	20–25	Mozambique	1993	1991	SADC, 1997
	11	South Africa		1995	*Energy Efficiency News,* 1996
Commercial/public/agriculture					
Electricity	20–25	Mozambique	1993	1995	SADC, 1997
	up to 50	Egypt	1998	1998	Alnakeeb and others, 1998
Agriculture/ forestry	12.5	Tanzania (biopower)	1993	1993	
Transportation					
Cars, road system	30	Nigeria		1985	Adegbulugbe, 1992a
Total transport	30	Ethiopia		1995	Mengistu, 1995

BOX 6.9. ENERGY-EFFICIENT COOKING IN RURAL AFRICA

The Kenya Ceramic Jiko initiative is one of the most successful urban cookstove projects in Africa. The initiative promotes a charcoal-based cookstove with an energy efficiency of about 30 percent. The stove is made of local ceramic and metal components. Since the mid-1980s more than 500,000 of the stoves have been produced and distributed in Kenya. The stove is not a radical departure from the traditional all-metal stove. Rather, it is an incremental development. On the other hand, the stove requires that charcoal be produced and transported.

The improved stove is fabricated and distributed by the same people who manufacture and sell traditional stoves. From the beginning the stove initiative received no subsidies—a decision that had a tremendous impact on its development, encouraging private entrepreneurs to invest their capital and work hard to recover their investment. This drive to recover the original investment helped ensure self-sustained production, marketing, and commercialisation of the charcoal stoves. In addition, the lack of subsidy enhanced competition between producers, bringing down its market price to a more realistic and affordable level for Kenya's low-income urban households. The stove design has been successfully replicated in Malawi, Rwanda, Senegal, Sudan, Tanzania, and Uganda.

Industry. Studies indicate that good housekeeping measures can save substantial amounts of energy in African industries (see table 6.12). Potential energy savings in national industries range from 15–32 percent by 2020. Results from energy audits in Nigeria (of two cement plants, one steel plant, and a furniture manufacturing plant) show potential savings of up to 25 percent. In 28 small- and medium-size industries in Zambia and Zimbabwe the potential savings are between 15 and 30 percent, in Kenyan industries about 25 percent, in nine industrial plants in Egypt about 23 percent, in Ghana 32 percent, and in Sierra Leone more than 20 percent. A more recent analysis carried out in industries in Mozambique indicates an economic electricity saving potential of 20 percent (SADC, 1997). Cogeneration also seems to have unexploited potential—in Egypt four industrial branches could save 600 megawatts by engaging in cogeneration (Alnakeeb, 1998).

Residential. The use of inefficient traditional three-stone fuelwood stoves for cooking, mainly in rural areas, results in considerable energy losses. The end-use efficiency of the stoves ranges from 12–18 percent. Promoting better biomass-cooking stoves and switching to modern fuels would greatly reduce the huge energy losses in this sector. Better cooking stoves could raise efficiency to 30–42 percent in Ghana, Kenya, and Uganda (box 6.9). In urban areas the focus should be on energy-efficient appliances, lighting, and other housekeeping measures for domestic appliances. In lighting a shift from kerosene to incandescent lamps, and from incandescent lamps to fluorescent and compact fluorescent lamps, would increase energy efficiency (see table 6.12).

Transportation. Road transport is the dominant mode in Africa. Nearly all vehicles are imported from overseas, often used cars and trucks. Potential savings are achievable by using roadworthy vehicles and changing policies. Vehicles tend to have low fuel efficiency. The average fuel efficiency in Nigeria is estimated to be about 18 litres of gasoline per 100 kilometres (Adegbulugbe, 1992a). Fuel efficiency is low because the vehicle fleet is old and poorly maintained, because of traffic congestion in most urban centres, and because of bad driving habits. Energy savings of 30 percent could be achieved in the road subsector by shifting from an energy-intensive transport mode to a less energy-intensive public transport system and by adopting traffic management schemes. In Ethiopia and Nigeria the demand for gasoline and diesel could be cut by 30 percent by emphasising public transportation over private automobiles (Adegbulugbe, 1992b; Mengistu, 1995).

The economic potential of energy efficiency—a systemic perspective

The preceding section covered only individual technology for energy conversion and use.[20] But additional—and sometimes major—energy savings can be realised by looking at energy-using systems in a broader sense. Aspects of this systemic view include:

- Optimising the transport and distribution of energy. Commercial energy use is often highly decentralised, yet the energy is produced in central plants; examples include electricity and district heating networks.
- Optimising the location of energy users to avoid transporting goods or people.
- Optimising according the second law of thermodynamics by supplying the suitable form of energy, including heat at the needed temperature and pressure, or by exploiting opportunities for energy cascading.

These concepts are not new. But they are often neglected in the planning of cities and suburbs, industrial sites and areas, airports, power plants, and greenhouses.

Excellent examples of the systemic approach include not only technical systems but also innovations in joint planning and coordinated—or even joint—operation or financing of energy generating, distributing, or using systems (IEA, 1997a):

- A district heating system in Kryukovo, Russia, that supplies almost 10 petajoules of heat was to a large extent manually controlled and monitored. Automated control of substations, remote sensing, and control between substations and the operator working station resulted in savings of 20–25 percent.
- Organising urban mobility is a major challenge for all countries. In areas with rapidly growing populations, planning decisions on residential, industrial, and commercial areas do not adequately consider induced mobility demand and possible modes of transportation. Incentives for car sharing, park-and-ride systems, and parking influence the use of cars and public transportation. In developing countries a lack of capital for subways must not lead to disastrous traffic jams. A possible solution has been realised by the bus system in Curitiba, Brazil (IEA, 1997a, p. 103).
- The adequate use of the exergy of energy carriers is another systemic aspect of energy efficiency. Cogeneration takes many forms: combined gas and steam turbines, gas turbines instead of burners, engine-driven cogeneration, and fuel cells that can supply heat at

Catalysts, enzymes, new materials, and new processes will make possible the substitution of many energy-intensive processes.

the correct levels of temperature and pressure (Kashiwagi, 1999). Excess heat at low temperatures may be used in heat transformers, heat pumps, or adsorption cooling systems. Production processes with high-temperature heat demand can be located in industrial parks surrounded by production processes with lower-temperature heat that can be reused in greenhouses or fish ponds (Kashiwagi, 1995).

These systemic aspects have been investigated less intensively because such systems demand a lot of coordinated planning and action by several actors and institutions. They often also demand changes in legal frameworks and decision-making in companies and administrations. Additional risks have to be managed by new entrepreneurial solutions and insurance services. In many cases, however, the efficiency potentials if such systems may exceed the economic efficiency potentials of individual technologies.

Technical and theoretical potentials for rational energy use after 2020

Many energy economists expect energy demand to increase in industrialised countries, accompanied by a substantial shift to natural gas, nuclear power, and renewables to avoid climate changes caused by energy-related greenhouse gases (chapter 9).[21] Explicitly or implicitly, those expectations assume that substantial cost-effective efficiency improvements will be exhausted within the next 20 years, contributing to new growth in energy demand after some 25 years of stagnation. But applied scientists and engineers have questioned the judgement that feasible improvements in energy efficiency are limited to 30–40 percent (Jochem, 1991; De Beer, 1998; ETSU, 1994; Blok and others, 1996; Kashiwagi and others, 1998). These authors argue that, depending on new technology and scientific knowledge, the long-term technical potential for rational energy use may even exceed 80 percent in the 21st century, driven by efforts to:

- *Increase exergy efficiency* (which today is less than 15 percent, even in industrialised countries) by exploiting the different temperatures of heat streams and using the adequate form of final energy or heat at the needed temperature level.
- *Decrease the level of useful energy* by reducing losses (for example, through insulation or heat recovery) and by substituting energy-intensive processes (such as membrane and absorption technologies instead of thermal separation, thin slab casting of steel instead of rolling steel sheets, new catalysts or enzymes, new bio-technical processes, and inductive electric processes instead of thermal surface treatment).
- *Apply new materials* (new compound plastics, foamed metals, nano-technology applications).
- *Intensify recycling of energy-intensive materials* (increased shares of recycled plastics, aluminium, or flat glass, which still have low recycling rates in most regions).
- *Re-substitute wood, natural fibres, and natural raw materials for energy-intensive plastics* (due to great potential for genetic manipulation of plants and substitution among energy-intensive materials; see box 6.1).

Because of the unbalanced perception between the long-term potential for rational energy use and energy conversion and supply technologies (Jochem, 1991), the huge long-term potential for increasing energy efficiency at the end-use level will likely remain underestimated for some time. Indeed, given the enormous economies of scale in fast-growing national, regional, and global markets, the economic efficiency potentials cited above for 2010 and 2020 may be too small in many cases.

To use as many energy sources as possible, the concept of cascaded energy use must be introduced in the energy conversion and end-use sectors. Cascaded energy use involves fully harnessing the heat produced by fossil fuel combustion (from its initial 1,700°C down to near-ambient temperatures), with a thermal 'down flow' of heat analogous to the downward flow of water in a cascade (Kashiwagi, 1995; Shimazaki and others, 1997). Applications that exploit the full exergetic potential of energy in multiple stages (cascaded) are not common. To exploit the exergetic potential of industrial waste heat, energy transfers between the industrial and residential or commercial sectors are advisable. But low energy prices make it difficult to find economically attractive projects.

For refrigeration, air conditioning, and hot water supply, it is possible to meet most of the heat demand with low-exergy waste heat obtained as a by-product of high-temperature, high-grade primary energy use in heat engines or fuel cells, in a cascaded use of cogeneration. From a thermodynamic viewpoint it is appropriate to combine low-exergy heat sources, such as solar and waste heat, with systems requiring low-exergy heat, such as heating, cooling, and air conditioning.

The level of specific useful energy demand can be influenced by innumerable technological changes without reducing the energy services provided by energy use and without impairing comfort. A few examples demonstrate these almost unconverted possibilities:

- The quality of insulation and air-tightness determine the demand for useful energy in buildings, furnaces, refrigerators and freezers. Low-energy houses need only 10–30 percent of the heat per square metre that is used in the average residential building in West Germany (box 6.12). A cold-storage depot or a refrigerator could be operated by outdoor air in the winter in zones with moderate climate.
- A substantial part of industrial waste heat occurs at temperatures below 50ºC. Water adsorption chillers provide a way to recover such heat sources and produce cooling energy (Saha and Kashiwagi, 1997), increasing energy efficiency.
- Catalysts, enzymes, new materials, and new processes will make possible the substitution of many energy-intensive processes. High energy demand to activate chemical reactions, with high-pressure and high-temperature processes, may be rendered unnecessary by new catalysts or biotechnological processes. Membrane processes will use only a small percentage of the useful

energy needed today in thermal separation processes. The production of iron—which today involves energy-intensive sintering and coke-making—will be switched to the new coal metallurgy, with substantial energy savings. Over the long term, the energy-intensive rolling-mill operation of steel-making will be replaced by continuous thin slab casting or even spraying of steel sheets.

- New materials for cutting edges will improve surface quality, avoiding several machine operations. Lasers will reduce the specific energy demand of metal cutting, and inductive electric processes will save energy in thermal surface treatment. New compound plastics or foamed metals will induce less energy demand in manufacturing and (because of smaller specific weight and reduced losses due to inertia) be used in vehicles and moving parts of machines and engines.

Over the past century energy systems in industrialised countries saw efficiency increase by 1.0–1.5 percent a year. Looking at the theoretical and technical potential of future energy efficiency, a similar increase of 1.0–1.5 percent a year appears possible over the next century. Increases in efficiency will be steadily exhausted by implementing economic efficiency opportunities and steadily fed by implementing technical innovations and cost reductions for energy-efficient technology. This process can be understood as a constant economic efficiency potential of 25–30 percent over the next 20 years, similar to the observation at the energy supply side that the ratio of proven reserves to consumption of oil remains at 30–40 years due to continuous searching for new reserves and technical progress on prospecting, drilling, and production techniques.

Obstacles, market imperfections, and disincentives for efficient energy use

Energy efficiency improvements since the oil shock of 1973 may have done more to redesign energy markets than did changes in conventional energy supply systems.[22] And as noted, such improvements still offer huge opportunities and can contribute to sustainable development in all regions. But given today's levels of energy-related knowledge, decision-making, and power structures, there is much evidence that the great potential for rational energy use will be overlooked by many companies, administrations, and households or deemed purely theoretical or unfeasible.

Of course, it will not be easy to fully achieve economic efficiency potentials, the 'fifth energy resource'. The technologies are decentralised and technologically very different, and increased efficiency is harder to measure than energy consumption. In addition, instead of a dozen large energy supply companies or a few engineering companies in a country, millions of energy consumers have to decide on their energy efficiency investments and organisational measures. The heterogeneity and diversity of energy consumers and manufacturers of energy-efficient equipment contribute to a low perception of the high potential of energy efficiency. Because of this variety and complexity, energy efficiency is not appealing for the media or for politicians (Jochem, 1991).

In theory, given all the benefits of energy efficiency at the microeconomic and macroeconomic levels, a perfect market would invest in, and allocate the rewards from, new energy-efficient technologies and strategies. 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). Although these obstacles and market imperfections are universal in principle, their importance differs among sectors, institutions, and regions.

General obstacles

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-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; Jochem, Sathaye, and Bouille, 2000).

OECD countries. Obstacles to and market imperfections for energy efficiency in end-use sectors have been observed in OECD countries for more than 20 years.[23] While limited, empirical research on the barriers underscores the diversity of individual investors (with thousands of firms, hundreds of thousands of landlords, and millions of consumers in a single country).

Lack of knowledge, know-how, and technical skills and high transaction costs. Improved energy efficiency is brought about by new technology, organisational changes, and minor changes in a known product, process, or vehicle. This implies that investors and energy users are able to get to know and understand the perceived benefits of the technical efficiency improvement as well as evaluate possible risks. It also implies that investors and users have to be prepared to realise the improvement and to take time to absorb the new information and evaluate the innovation (OTA, 1993; Levine and others, 1995; Sioshansi, 1991). But most households and private car drivers, small and medium-size companies, and small public administrations do not have enough knowledge, technical skills, and market information about possibilities for energy savings. The construction industry and many medium-size investment firms face the same problem as small companies on the user's side. Managers, preoccupied with routine business, can only engage themselves in the most immediately important tasks (Velthuijsen, 1995; Ramesohl, 1999). Because energy efficiency reduces a small share of the energy costs of total production or household costs, it gets placed on the back burner.

Lack of access to capital and historically or socially formed investment patterns. The same energy consumers, even if they gain knowledge, often have trouble raising funds for energy efficiency investments. Their capital may be limited, and additional credit may be expensive. Especially when interest rates are high, households and small firms tend to prefer to accept higher current costs and the risk of rising energy prices instead of taking a postponed energy credit (DeCanio, 1993; Gruber and Brand, 1991).

> Because energy efficiency reduces a small share of the energy costs of total production or household costs, it gets placed on the back burner.

Disparity of profitability expectations of energy supply and demand. The lack of knowledge about energy efficiency among small energy consumers raises their perceptions of risk, so energy consumers and suppliers expect different rates of return on investments (Hassett and Metcalf, 1993). Energy supply companies in countries with monopolistic energy market structures are willing to accept nominal internal rates of return of 8–15 percent (after tax) for major supply projects (IEA, 1987). But for efficiency investments, energy consumers demand—explicitly or without calculating—payback periods between one and five years, which are equivalent to a nominal internal rate of return of 15–50 percent (DeCanio, 1993; Gruber and Brand, 1991). This disparity in rate of return expectations also seems to apply to international loans, putting energy efficiency investments in developing countries at a disadvantage (Levine and others, 1995).

The impact of grid-based price structures on efficient energy use. Grid-based forms of energy play a dominant role in OECD countries. The structure of gas, electricity, and district heat tariffs for small consumers and the level of the load-independent energy charge are important for energy conservation. Tariff structures are designed in two parts to reflect two services—the potential to obtain a certain amount of capacity at any given time, and the delivered energy. The capacity charge plays an important role in profitability calculations for investments where efficiency improvements do not reduce capacity demand, such as inverters on electric engines or control techniques in gas or district heating (IEA, 1991). In addition, in most OECD countries utilities still do not offer time-of-use or seasonal rates to small consumers, which would reward them for using energy during off-peak hours. This, however, may change in fully liberalised electricity and gas markets.

Legal and administrative obstacles. There are legal and administrative obstacles in almost all end-use sectors. They are mostly country specific, and often date back to before 1973, when energy prices were low and declining in real terms and there was no threat of global warming. For most local government authorities the budgeting format is an 'annual budgeting fixation', which means that they cannot transfer funds from the recurrent to the investment budget. With a lot of other urgent needs calling for capital investment, energy efficiency measures are given low priority. The poor perception of public goods adds to the obstacles confronting energy efficiency in developing and transition economies (see below).

Other market barriers. The investor-user dilemma points to the fact that for rented dwellings or leased buildings, machines, or vehicles, there are few incentives for renters to invest in property that they do not own. Similarly, landlords, builders, and owners have few incentives to invest because of the uncertainty of recovering their investment through higher rent (Fisher and Rothkopf, 1989; Golove, 1994). Finally, the quality of delivered energy (as with unstable frequencies or voltages of electricity or impurities in gasoline or diesel) may pose a severe barrier for efficiency investments (electronic control or high efficiency motors).

Additional barriers in transition economies.[24] Transition economies did not experience the sharp increase in world energy prices in the 1970s. As a result opportunities for more efficient energy use were scarcely realised in these countries. Most transition economies suffer from all the barriers described above for OECD countries, as well as from additional market problems stemming from the legacy of central planning. The deep economic and structural crisis during the early years of transition shifted the investment priorities of industrial and commercial companies to short-term decisions, helping them to survive. Technological innovations that increase energy efficiency are hardly considered a priority in many transition economies (Borisova and others, 1997). There are, however, substantial differences among most Eastern European countries and members of the Commonwealth of Independent States.

Unpaid energy bills. The economic crisis in transition economies created special obstacles to investing in energy efficiency, including non-payments and non-monetary payments (barter, promissory notes, and other surrogates by energy consumers, mutual debt clearing between companies). In Georgia less than 30 percent of residential electricity rates were paid in 1994; industrial payments fell to 16 percent, and 25–50 percent of the electricity supply was not accounted or billed (World Bank, 1996; TACIS, 1996). In Russia about 25 percent of generated electricity was not paid for by customers in 1995–97 (BEA, 1998). Industrial and commercial customers covered up to 80 percent of their energy bills using non-monetary and surrogate means (Russian Federation Ministry of Fuel and Energy, 1998). The use of barter is contributing to the neglect of potential reductions in energy costs through efficiency measures. Experience in Eastern Europe, however, demonstrates that cutting customers off from the electricity or gas supply persuades them to pay (box 6.10).

BOX 6.10. THE IMPLICATIONS OF TERMINATING ELECTRICITY SUBSIDIES IN HUNGARY

Raising energy prices to cost-covering levels can produce miracles. Until 1997 Hungary spent $5–10 million a year on energy efficiency improvements. In January 1997 energy prices were raised to market-based levels—and in just two years, investments in energy efficiency jumped to $80 million a year. The usual argument against correct energy pricing, that consumers cannot pay the bills, is not proven in Hungary. Just 10 percent of the national energy bill remained unpaid, and that just partly. True, retirees with low incomes have difficulties. But they are not the big consumers with high bills. The problem is a social problem, and has been solved by special payment schemes in the social policy framework of local and national budgets.

Subsidised energy prices reduce the economic attractiveness of energy efficiency measures.

Barriers to energy metering. Many energy customers in transition economies are still not equipped with meters and controllers or have simplistic, outdated meters. In particular, residential customers in the Commonwealth of Independent States often have no meters to measure the use of natural gas, heat, and hot water, reflecting a long-held view that heat and fuel are public goods. According to the Russian Federation Ministry of Fuel and Energy (1998), only about 10 percent of heat customers (and no more than 15 percent of hot water and natural gas customers) are equipped with meters. Since 1994, however, significant efforts have been made to manufacture modern meters and controllers and to develop related services (certification, maintenance, and verification) (Minfopenergo, 1996). Meters are far more common in Eastern Europe, because since the 1980s these countries have had to import needed energies in exchange for hard currency.

Lack of cost-based tariffs for grid-based energies. Natural gas, electricity, heat, and hot water are supplied to users in the Commonwealth of Independent States and some Eastern European countries by regional or local energy monopolies with government participation and municipal distribution companies. Energy tariffs are still set by federal and regional energy commissions in most of the Commonwealth of Independent States. In Russia a large portion of customers are subsidised; fuels are of poor quality, expensive, or both; resellers charge excessive costs and receive large profits; detailed information is lacking on the production costs of suppliers; and the decisions of regional commissions do not sufficiently reflect cost considerations, but depend on the political priorities of the local authorities (Vasiliev and others, 1998).

Subsidies. In all Commonwealth of Independent States countries and a few Eastern European countries the grid-based energy supply of residential and agricultural customers is still subsidised. Subsidies are driven by traditional concepts of public goods or social policy. In addition, some groups (war veterans, low income families) pay discounted residential tariffs. In Ukraine the government paid 20 percent of the cost of natural gas for residential customers in 1996 (Gnedoy, 1998). Russian municipalities spend 25–45 percent of their budgets on residential heat subsidies, covering more than half of heat bills (Bashmakov, 1997a).

Subsidised energy prices reduce the economic attractiveness of energy efficiency measures. Cross-subsidies for electric power in the Commonwealth of Independent States distort price signals between groups of customers. For instance, cross-subsidies for residential electricity account for 20–60 percent of prices for industrial customers in different regions of Russia (Moloduik, 1997; Kretinina, Nekrasov, and Voronina, 1998). In principle, this price structure would lead to large investments in efficiency in Russian industry. But non-payment of energy bills prevents that from happening. The case for abolishing electricity subsidies in most Eastern European countries demonstrates that the social aspects of such a pricing policy can be addressed by social policy at the municipality level (see box 6.10).

Additional barriers in developing countries. The general obstacles to efficient energy use are sometimes more intense in developing countries than in OECD or transition economies.[25] But there are similarities between subsidies and pricing policies in developing and transition economies. The situation in developing countries may be more complex given the big differences in energy use, income, development, and infrastructure between urban and rural areas in India, China, Latin America, and Africa.

Lack of awareness of potential benefits. The limited awareness of the potential for energy efficiency is the most important obstacle to wide-scale adoption of energy efficiency measures and technologies in developing countries. Limited awareness is a by-product of inadequate information infrastructure to raise awareness of the potential for energy efficiency and of available technologies and proven practices. The media used to raise awareness in most developing countries limit the audience. Awareness campaigns rely on radio, television, and newspapers, which most rural populations—the majority of the population in developing countries—do not have access to. In addition, managers in industry do not have timely information on available efficiency technology (Reddy, 1991), and many producers of end-use equipment are unacquainted with energy-efficient technology and related knowledge.

Many developing countries still lack an effective energy efficiency policy at the national level. Energy supply policies are preferred in most developing countries because of the focus on development policies. This pattern may also be due to the fact that grid-based energy supplies are often owned by national or local governments, a pattern that supports rigid hierarchical structures and closed networks of decision-makers.

Energy supply constraints. In some developing countries, energy supply constraints provide no alternative fuel and technology options for consumers. The limited availability of commercial fuels (petroleum products, electricity) in rural areas impedes switching to more energy-efficient stoves, dryers, and other technologies, posing a major challenge for energy policy (see chapter 10).

Inappropriate energy pricing and cross-subsidies. Energy prices are still below marginal opportunity costs in many developing countries, reflecting the desire of governments to use energy supply to achieve political objectives. Successive governments have upheld energy subsidies over decades, making it politically difficult to raise energy prices to the level of marginal opportunity costs (box 6.11; Nadel, Kothari, and Gopinath, 1991).

Lack of trained staff, operators, and maintenance workers. Insufficient energy workers are an important constraint to the investment and operation of buildings, machines, plants, and transport systems (Suzuki, Ueta, and Mori, 1996).

Lack of capital and import of inefficient used plants and vehicles. Many energy efficiency measures are delayed by a lack of financing. The availability of credit at high interest rates tends to make energy efficiency investments a low priority. In many developing countries there is also a conflict among investment priorities. Growing economies generally favour investments in additional capacity over investments in energy efficiency. This tendency and lack of capital lead to imports of used plants, machinery, and vehicles, aggravating the problem (see the section on technology transfer, above).

Proliferation of inefficient equipment and the desire to minimise initial costs. In the absence of energy labelling schemes and of standards for energy efficiency, energy-inefficient products continue to be manufactured and marketed. Examples include diesel-fuelled irrigation pumps, motors, and transformers. Many users focus on minimising initial costs, with little regard for operating efficiency and life-cycle costs. Thus they tend to opt for cheaper, locally manufactured, inefficient equipment.

Target group-specific and technology-specific obstacles

Many target group–specific and technology-specific obstacles also impede investments in energy efficiency.[26]

Buildings. Lack of information and knowledge is a problem not only among building owners, tenants, and users in *industrialised countries,* but also among architects, consulting engineers, and installers (IEA, 1997a; Enquête Commission, 1991). These groups have a remarkable influence on the investment decisions of builders, small and medium-size companies, and public authorities. The separation of spending and benefits (or the landlord-tenant dilemma) is common in rented buildings because the owner of a building is not the same as the user (IEA, 1991). This obstacle impedes the adoption of efficient space heating, air conditioning, ventilation, cooling, and lighting equipment in leased buildings and appliances. It is also a problem in the public sector, where schools, sports halls, hospitals, and leased office buildings may have a variety of owners—or where local governments operate and use buildings owned by state or federal governments. Building managers are often not sufficiently trained and do not receive adequate incentives for excellent performance. Planners and architects are often reimbursed based on the total investment cost, not the projected life-cycle cost of the planned building or equipment.

In many *developing countries* building design has been imitated from industrialised countries regardless of different climates, domestic construction materials, and construction traditions. This approach often results in an extremely energy-consuming design for cooling equipment in office buildings in warm developing countries. Houses in higher-income developing countries are often built by the affluent with a view to projecting prestige rather than reflecting economic concerns. Such buildings are generally devoid of energy efficiency aspects. Lack of information on energy-efficient architecture also undermines energy-efficient building standards and regulations. And in countries where such standards and regulations exist, non-compliance is a constraint.

Household appliances and office automation. Residential consumers in *industrialised countries* substantially underinvest in energy-efficient appliances or require returns of 20 to more than 50 percent to make such investments (Sioshansi, 1991; Lovins and Hennicke, 1999). Related obstacles include a lack of life-cycle costing in a culture of convenience, longstanding ties to certain manufacturers, aspects of prestige, and the investor-user dilemma in the case of rented apartments or office equipment.

Low incomes make it difficult for households in *developing countries* to switch from lower efficiency to higher efficiency (but more expensive) devices (improved biomass cook stoves, and liquefied petroleum gas and kerosene stoves). Similarly, fluorescent and compact fluorescent lamps are often not bought due to the lack of life-cycle costing by households.

Small and medium-size companies and public administration. In most small and medium-sized companies, all investments except infrastructure are decided according to payback periods instead of internal interest rate calculations. If the lifespan of energy-saving investments (such as a new condensing boiler or a heat exchanger) is longer than that of existing production plants and machinery and if the payback period is expected to be even for both investments, entrepreneurs expect (consciously or unconsciously) higher profits from energy-saving investments (table 6.13).

Lack of funds is a severe constraint for small and medium-size local governments in many countries. Many communities with high

BOX 6.11. DISTORTED ENERGY PRICES RESULT IN BIG LOSSES FOR INDIAN SUPPLIERS

Distorted energy prices are a major obstacle to energy efficiency. In India electricity tariffs vary considerably between states and types of users. The average cost of supply for the country's electricity boards is $0.049 a kilowatt-hour—yet revenue collection averages just $0.037 a kilowatt-hour. Utility losses are mounting and were reported to be $1.49 billion in 1994/95 (GOI, 1995). High commercial losses are mainly caused by the irrational tariff structure, which provides large subsidies to agricultural and domestic uses (see table).

Electricity tariffs in Indian states, 1998 (U.S. cents per kilowatt-hour)

State electricity board	User						
	Domestic	Commercial	Agriculture/ irrigation	Industry	Rail transport	Exports to other states	Average
Haryana	4.7	7.5	1.2	7.5	7.5	3.2	5.3
Himachal Pradesh	1.6	4	1.4	3.5	n.a.	3.5	2.8
Jammu, Kashmir	0.7	1.2	0.2	0.9	n.a.	n.a.	0.8
Kerala	1.4	4.6	0.5	2.4	n.a.	n.a.	2.2
Madhya, Pradesh	1.7	7.3	0.1	7.4	11.8	2.1	5.1
West Bengal	1.9	4.7	0.6	5.9	6.7	n.a.	3.3
Average	**2.9**	**6.7**	**0.5**	**6.9**	**8.5**	**2.9**	**4.1**

n.a. Not available.

Source: Ministry of Power, Government of India (http://powermin.nic.in/plc72.htm).

unemployment are highly indebted. Making matters worse, municipalities often receive a significant share of their annual budgets through some kind of tax or surcharge on electricity, gas, or district heat sales to their residents, lowering the enthusiasm of local politicians for promoting energy conservation. Finally, in public budget planning, budgets for operating costs are often separate from budgets for investment. Thus possible savings in the operating budget from energy efficiency investments are often not adequately considered in the investment budget.

For small and medium-sized enterprises and communities, installing new energy-efficient equipment is far more difficult than simply paying for energy (Reddy, 1991). Many firms (especially with the current shift towards lean firms) suffer from a shortage of trained technical staff (OTA, 1993) because most personnel are busy maintaining production. In the Netherlands a lack of available personnel was considered a barrier to investing in energy-efficient equipment by one-third of surveyed firms (Velthuijsen, 1995).

Insufficient maintenance of energy-converting systems and related control equipment causes substantial energy losses. Outsiders (external consultants, utilities) are not always welcome, especially if proprietary processes are involved (OTA, 1993). Many companies cannot evaluate the risks connected with new equipment or control techniques in terms of their possible effects on product quality, process reliability, maintenance needs, or performance (OTA, 1993). Thus firms are less likely to invest in new, commercially unproven technology. An aversion to perceived risks is an especially powerful barrier in small and medium-size enterprises (Yakowitz and Hanmer, 1993).

In *transition economies* small companies and local authorities may not be able to afford an energy manager.

In *developing countries* lack of information and technical skills is an enormous problem for small and medium-sized firms, because such firms often account for a large portion of the economy. In addition, the possible disruption of production is perceived as a barrier to investments in energy efficiency. Although such an investment may be economically attractive, unexpected changes in production increase the risk that the investment will not be fully depreciated.

Large enterprises and public administrations. Mechanisms are often lacking to acknowledge energy savings by local administrations, public or private. Public procurement is generally not carried out on the basis of life-cycle cost analysis. Instead, the cheapest bidder gets the contract—and as long as the offered investment meets the project's specifications for energy use, it need not be energy efficient. The industrial sector, where managers are motivated to minimise costs, poses the fewest barriers to energy-efficient investment (Golove, 1994). But DeCanio (1993) shows that firms typically establish internal hurdle rates for energy efficiency investments that are higher than the cost of capital to the firm. This fact reflects the low priority that top managers place on increasing profits by raising energy productivity.

Developing countries often lack sufficient human resources to implement energy efficiency projects and to adequately operate and service them. Thus, even when firms recognise the potential of energy efficiency and want to harness the benefits of energy efficiency measures, they are often hampered by a dearth of skilled staff and consultants and by a lack of competent energy service companies. Capital constrains also impede rational energy use in these countries. Furthermore, low capacity use (sometimes as low as 30 percent; World Bank, 1989) affects efficient energy use by industry. Low capacity use is caused by many factors, including poor maintenance, lack of spare parts and raw materials, and unsuitable scale and design of plants.

These factors are often complicated by the risk-averse management of big firms. This attitude usually stems from resistance to change, limited knowledge on the technical and economic analysis of energy efficiency technology, and a paucity of data on the experiences of previous users of such measures or technology.

Transportation. The transport policies of most countries rarely view transportation as an energy issue. Rather, transportation is considered a driver of economic growth with the development of infrastructure for moving goods and people. This policy is strongly supported by associations of car drivers, the road transport and aviation industries, and vehicle manufacturers. Most countries have no fuel efficiency standards for new vehicles; the exceptions are for cars as in Canada, Japan, and the United States (Bradbrook, 1997) and a recent voluntary agreement among Western European car manufacturers to improve fuel efficiency by 25 percent between 1995 and 2008. In nearly all countries, cars owned by companies or public authorities are often inappropriately powered. Bad driving habits, especially of government- and company-owned vehicles, also impede the rational use of energy in road transportation.

The benefits of fuel efficiency standards are evident from the success of mandatory Corporate Average Fuel Economy (CAFE) standards being introduced in North America (though the standards do not apply to light vehicles). Many voters in *OECD countries* consider driving a car to be an expression of individual freedom. As a result most drivers and politicians do not pay much attention to fuel efficiency.

TABLE 6.13 PAYBACK CALCULATIONS AS A RISK INDICATOR LEAD TO UNDER-INVESTMENT IN PROFITABLE, LONG-LASTING ENERGY EFFICIENCY INVESTMENTS

Payback time requirement (years)	Useful life of plant (years)							
	3	4	5	6	7	10	12	15
2	24%	35%	41%	45%	47%	49%	49.5%	50%
3	0%	13%	20%	25%	27%	31%	32%	33%
4		0%	8%	13%	17%	22%	23%	24%
5			0%	6%	10%	16%	17%	18.5%
6				0%	4%	10.5%	12.5%	14.5%
8	Unprofitable					4.5%	7%	9%

Note: Percentages are annual internal rates of return. Continuous energy saving is assumed over the entire useful life of the plant. Profitable investment possibilities are eliminated by a four-year payback time requirement.

> Low incomes make it difficult for households in developing countries to switch from lower efficiency to higher efficiency (but more expensive) devices.

The weak finances of local and national governments in *transition economies* make it difficult to introduce modern public transport systems or to upgrade existing ones. The limited financial resources of households and small companies are the main reason for heavy imports of used cars from Western Europe and Japan.

In *developing countries* road transportation increases mobility without the huge public upfront investment needed for railways, subways, and trams. Thus one major obstacle to improved energy efficiency is the limited number of alternative transport modes. In many developing countries vehicles are either assembled or imported. Economic problems and devaluations of local currencies have driven up vehicle prices. As a result many people and small firms cannot afford new vehicles, so a lot of car buyers opt for imported used vehicles that have been used for several years in the country of origin. Similar problems are being encountered with the pricing of spare parts. In addition, most developing countries lack regulation on regular car inspections. Together these problems have resulted in poor vehicle maintenance that has exacerbated energy inefficiency.

The Intergovernmental Panel on Climate Change report on aviation (IPCC, 1999a) projects a 20 percent improvement in fuel efficiency by 2015 and a 40 percent improvement by 2050 relative to aircraft produced today. Improvements in air traffic management would reduce fuel demand by another 8–18 percent. Environmental levies and emissions trading can help realise these improvements by encouraging technological innovation and reducing the growth in demand for air travel.

Agriculture. Agriculture is the main beneficiary of subsidised electricity in *developing countries.* In some cases electricity is even provided to agricultural consumers free of charge. One major fallout of this approach is the phenomenal growth in electricity consumption by this sector. In the 1980s agriculture consumed 18 percent of India's electricity; by 1994 it consumed 30 percent (CMIE, 1996). Even after accounting for the additional pump sets installed during this period, extremely low electricity prices are one of the main reasons for the increase in the sector's energy intensity.

Cogeneration. Cogeneration has considerable potential in industrial sites and district heating systems. Yet the monopolistic structure of the electricity sector in many countries has led to high prices for maintenance and peak power, rather low buyback rates and costly technical standards for grid connection, and to dumping prices in the case of planning new cogeneration capacity (VDEW, 1997). As a result many auto producers restrict the capacity of the cogeneration plant to their minimum electricity and heat needs, although they may wish to produce more heat by cogeneration. This situation is changing now in countries (such as France) with liberalised electricity markets and regulated or competitive buyback rates.

In *Central and Eastern Europe* centralised district heating remains a widespread solution for heating big housing estates. The economics of centralising the heat supply of a certain area is regarded not as a question of profitability, but a historical fact. But inadequate pricing, inefficient operation, mismanagement, and lack of full use of cogeneration potential are encouraging heat consumers to disconnect from the district heating grid. The easy availability of natural gas, existence of small and medium-size cogeneration units (namely, gas engines and gas turbines), and desire for independence also encourage consumers to disconnect. This tends to make the heat demand density leaner, driving the system in a negative spiral that may end in the economic collapse of many district heating enterprises in transition economies.

The potential for industrial cogeneration is estimated at 20–25 percent of industrial and commercial electricity demand in several *developing countries* (TERI, 1994; Alnakeeb, 1998). India's sugar industry, for instance, generates 3,500 megawatts of bagasse-based cogenerated power. But the full potential of industrial cogeneration in China, India, and Latin America has yet to be realised because of slow progress on power buyback arrangements and the wheeling and banking of cogenerated power by state electricity boards. Although institutional barriers are considered the main obstacle in this regard, limited indigenous capacity to manufacture high-pressure boilers and turbines is also an important barrier, as hard currency is scarce in developing countries (TERI, 1994).

For every obstacle and market imperfection discussed in this section, there are interrelated measures of energy efficiency policy that could remove or reduce them (figure 6.5). But the choice of which policies to pursue must be made with care, because their effectiveness depends on many regional, cultural, and societal circumstances and on the different weights of the obstacles in different regions.

National and international policies to exploit the economic potential of energy efficiency in end-use sectors

Despite the clear warnings of the scientific community (IPCC, 1995) and the commitments made under the Kyoto Protocol, and despite possible reductions in energy costs and the benefits of energy efficiency for employment and economic development (see box 6.3), many scientists and non-governmental organisations (NGOs) feel that "policy makers are still doing too little to use energy efficiency potentials in order to safeguard their citizens and their future" (Lovins and Hennicke, 1999, pp. 7–10; Phylipsen, Blok, and Hendriks, 1999; further citations).[27] These authors ask for more activity in policy areas such as energy efficiency, transportation, and renewables.

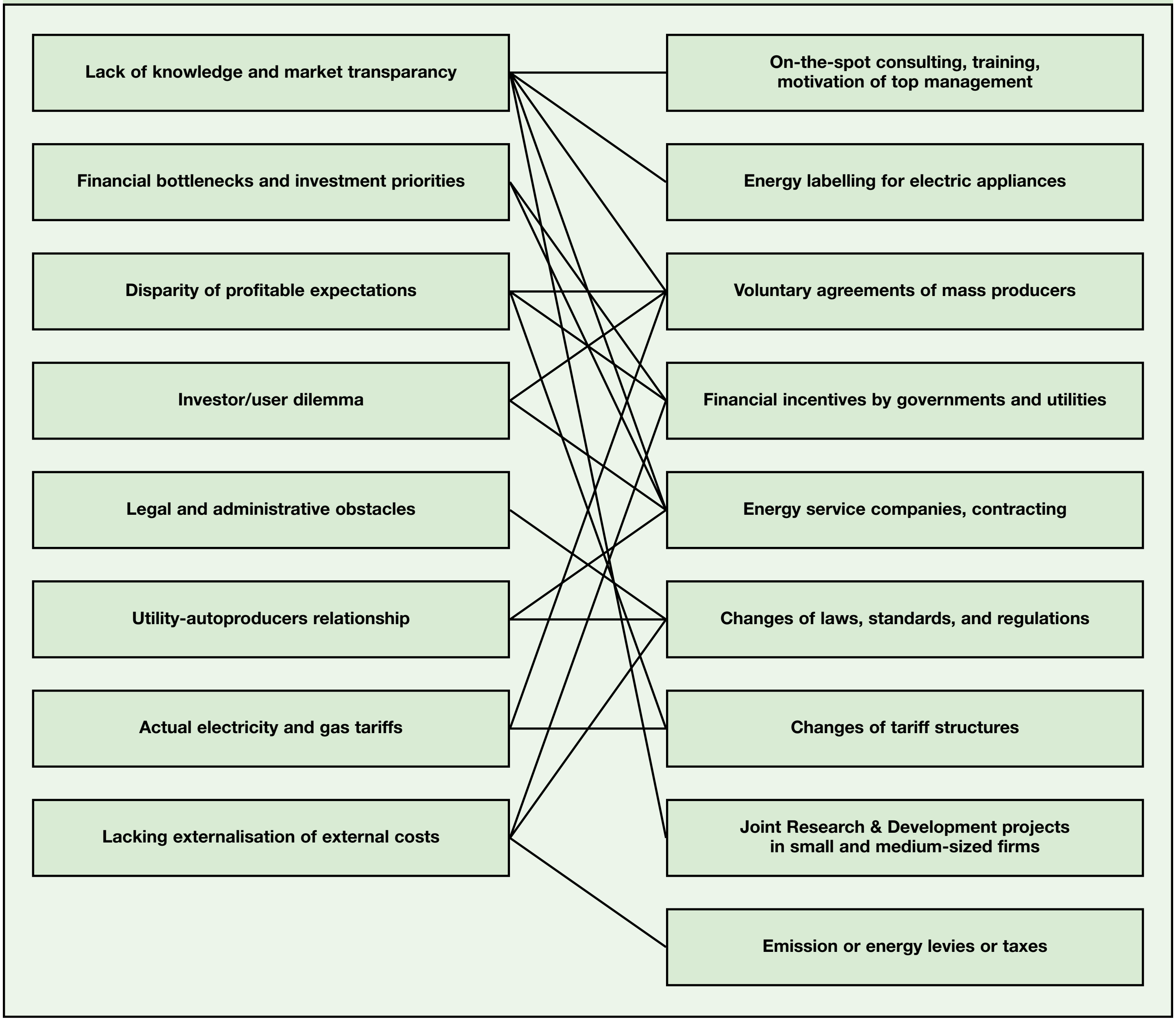
Over the past 25 years individual and ad hoc policy measures—such as information, training, grants, or energy taxes—have often produced limited results (Dasgupta, 1999). But integrated energy demand policies—which consider simultaneous obstacles and the interdependence of regulations, consultations, training programmes, and financial incentives—and long-lasting programmes have been relatively successful. Energy demand policy is not only initiated by governments. Companies, utilities, industrial associations, and NGOs may also play an important part.

An integrated energy, transportation, financial, and economic policy is one of the main opportunities for realising the huge economic energy saving potentials not only of individual parts and technologies, but also of a country's energy-using systems. There is a strong need to formulate a long-term strategy that promotes energy efficiency improvements in all sectors of the economy and that takes into account general obstacles, market imperfections, and target group–specific barriers. This section presents the policy initiatives to be taken in different end-use sectors in a linear manner, but such initiatives have to be implemented together to contribute to sustainable development (see figure 6.5). These policies include general policy instruments such as energy taxes, direct tax credits, emissions trading, a general energy conservation law, general education on energy issues in schools, and research and development (see chapter 11). In some cases international cooperation by governments and industrial associations may play an important supporting role.

General policy measures

General policies to promote energy efficiency try to overcome general obstacles and market imperfections. They may also be implemented

FIGURE 6.5. OBSTACLES AND MARKET IMPERFECTIONS FOR ENERGY EFFICIENCY AND RELATED POLICIES: A SCHEME FOR POLICY OPTIONS AND INTEGRATED EFFICIENCY POLICY



in the context of broader economic issues, such as shifting the tax burden from labour to non-renewable resources through an ecotax at the national or multinational level (see chapter 11). Or new regulation may be needed to limit the ambiguous impacts of liberalised electricity and gas markets in their transition phase.

> Energy demand policy is not only initiated by governments. Companies, utilities, industrial associations, and NGOs may also play an important part.

The acceptance of such policy measures differs by country and varies over time depending on how much an energy policy objective is violated or in question. Energy efficiency policy was widely accepted in OECD countries in the 1970s and early 1980s, when dependence on oil imports from OPEC countries was high and higher fuel prices had changed cost structures and weakened competitiveness in energy-intensive industries. With declining world energy prices between 1986 and 1999, reduced dependence on energy imports in many OECD countries, and stagnating negotiations on the implementation of the Kyoto Protocol, public interest in energy efficiency policy has fallen in many OECD countries.

By contrast, energy efficiency receives considerable attention from governments, industries, and households in Eastern European countries, in some Commonwealth of Independent States countries without indigenous energy resources, and in many emerging economies facing problems with sufficient and reliable supplies of commercial energy.

Energy conservation laws have been passed in many countries (Australia, Canada, China, Finland, Germany, Japan, Russia, Switzerland, the United States) or are in the process of being passed (India). Such laws are important for establishing a legal framework for sector regulation (building codes, labelling, technical standards for equipment and appliances) and for implementing other measures (energy agencies, financial funds for economic incentives or public procurement). In many countries with federal structures, however, much of the legislative power to enact energy conservation laws rests with individual states—posing problems for compliance and joint action.

Education on energy efficiency issues in primary or secondary schools, along with professional training, raises consciousness and basic knowledge about the efficient use of energy and the most recent technologies.

Direct subsidies and tax credits were often used to promote energy efficiency in the past. Direct subsidies often suffer from a free-rider effect when they are used for investments that would have been made anyway. Although it is difficult to evaluate this effect, in Western Europe 50–80 percent of direct subsidies are estimated to go to free riders (Farla and Blok, 1995). Low-interest loans for energy efficiency projects appear to be a more effective subsidy, although they may have a distribution effect.

Energy service companies are a promising entrepreneurial development, as they simultaneously overcome several obstacles by providing professional engineering, operational, managerial, and financial expertise, along with financial resources. Such companies either get paid a fee based on achieved savings or sign a contract to provide defined energy services such as heating, cooling, illumination, delivery of compressed air, or hot water.

Transition economies. From a policy perspective, efficient energy use creates enormous opportunities in light of huge reinvestments in industry and infrastructure and large new investments in buildings, vehicles, and appliances. In the Commonwealth of Independent States and Eastern Europe increased energy efficiency was made a top political priority in the early and mid-1990s—as with Russia's 1994 National Energy Strategy (IEA, 1995). But according to the Russian Federation Ministry of Fuel and Energy (1998), government support for such activities was less than 8 percent of the planned funding in 1993–97.

Transition economies that were relatively open under central planning (defined as those for whom foreign trade accounted for more than 30 percent of GDP) have had an easier time adjusting to world markets. Multinational companies from Western Europe and other OECD countries maintain their technical standards when building new factories in transition economies. In addition, Eastern European countries are trying to approach (and later, to meet) Western European technical standards as part of their eventual accession to the European Union (Krawczynski and Michna, 1996; Michna, 1994).

Energy efficiency policies developed differently according to the speed of transition and economic growth in these countries. Some elements of efficiency programmes have been quite successful despite economic difficulties: laws, energy agencies, energy auditing of federal buildings. In most transition economies the first energy service companies were established with the support of international institutions. Some industrial enterprises established internal energy monitoring and control, reinforced by incentives and sanctions for particular shops and their management. The results of such activities differed considerably among transition economies, reflecting levels of organisation, human and financial capital, trade experience, foreign investment, energy subsidies, and other factors.

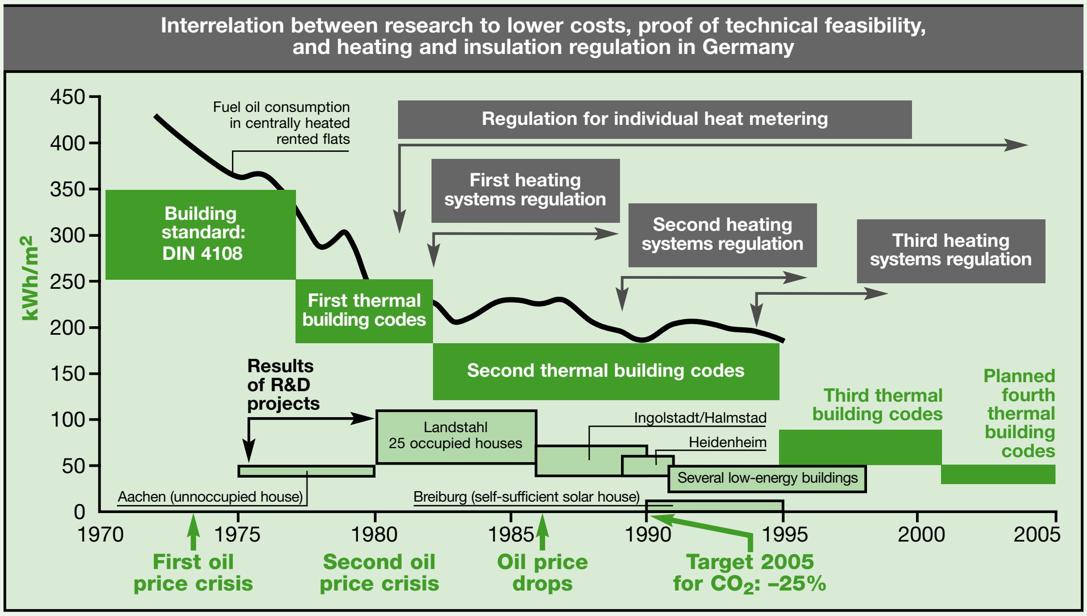
Developing countries. The phasing out of substantial energy subsidies can often be complemented by capacity building, professional training, and design assistance. Utilities in Mexico and Brazil, for example, have been active in demand-side management programmes with cost-benefit ratios of more than 10 to 1 (Dutt and others, 1996). Given the shortage of capital in many developing countries, financial incentives seem to have a large impact on energy efficiency (unlike in OECD countries). An example is China in the 1980s, where such incentives contributed to the remarkable decline in China's industrial energy intensity (Sinton and Levine, 1994).

Sector- and technology-specific policy measures

Given the many obstacles that keep economic energy-saving potential from being realised on a sectoral or technological level, any actor will look for a single instrument that can alleviate all obstacles. For mass products, performance standards are considered an efficient

BOX 6.12. THE MULTIMEASURE CHARACTER OF NATIONAL ENERGY EFFICIENCY POLICY— A 20-YEAR LEARNING CURVE FOR MULTIFAMILY BUILDINGS IN WEST GERMANY

After the oil shocks of the 1970s, German professional organisations made recommendations for new building standards. In addition, the federal government enacted an ordinance for boiler efficiencies to accelerate the replacement of old boilers by new, more efficient ones. Building codes and boiler standards have since been tightened three times, and regulations on individual heat metering were introduced in the early 1980s. Research and development enabled the new standards to be met. Twenty-five years later, the results are convincing. New buildings are 50–70 percent more efficient, and retrofits have cut energy consumption by 50 percent in Germany (and by at least 30 percent in most Western European countries).



Source: EC, 1999b.

instrument because they can be developed after discussions with scientists, engineers, and industrial associations, manufacturers, and importers. Standards and labelling avoid the need for information, high transaction costs, and dissemination to, consultations with, and training of millions of households, car drivers, and small and medium-size companies (Natural Resources Canada, 1998).

But no single, highly efficient instrument will be available in all cases (as with the refurbishing of buildings or efficiency improvements in industrial plants). In these cases a package of policy measures has to be implemented to alleviate obstacles (see figure 6.5).

Buildings. There seems to be an intellectual barrier between planners and architects for buildings in cold and warm climates, although building codes may offer huge efficiency potential in most countries. Jochem and Hohmeyer (1992) conclude that if comprehensive policy strategies are implemented, governments will discover that the economics of end-use efficiency are far more attractive than is currently believed. A good example is the refurbishing of residential buildings. Homes and apartment buildings consume about 20 percent of final energy in many countries. Refurbishing a building may be primarily an individual event, but its effectiveness depends on such political and social remedies as:

- Advanced education and training of architects, planners, installers, and builders, as carried out in the Swiss 'impulse programme', which has had outstanding results since 1978.
- Information and education for landlords and home owners (particularly on the substitution of energy costs for capital costs).
- Training professional advisers to perform audits and provide practical recommendations. These audits should be subsidised; otherwise they may be considered too costly by landlords or home owners. Such subsidies have proven cost-effective.
- Investment subsidies tied to a registered energy consultant and a formal heat survey report and minimum energy efficiency level.
- Investment subsidies for specific groups of home owners or multifamily buildings to overcome financial bottlenecks or risks of the investor-user dilemma. The cost-effectiveness of such subsidies has often been overestimated, however.
- Economically justified insulation and window design secured by new building codes that also cover the refurbishing of buildings.
- Research and development to improve building design (low-energy houses, passive solar buildings), insulation material, or windows, or to reduce construction costs.

Energy-saving programs in Denmark, Finland, Germany, Sweden, and Switzerland owe much of their success to this multimeasure approach, which is increasingly being adopted by other countries (box 6.12). The combination of measures has increased capacity in the construction sectors of those countries. Energy labelling for buildings has been introduced in a few OECD countries and is being considered in several others (Bradbrook, 1991). Such labelling provides information on a building's energy costs when it is being rented or bought (Hicks and Clough, 1998). Building standards for cooling have been adopted in Indonesia, Mexico, Singapore, and Thailand. Compliance with building codes is uncertain in many countries, however, because (expensive) controls are lacking (Duffy, 1996).

Household appliances and office automation. Household appliances and office equipment are well suited for technical standards and labelling. Varone (1998) compared instruments used between 1973 and 1997 in Canada, Denmark, Sweden, Switzerland, and the United States to promote energy-efficient household appliances and office equipment. About 20 instruments were identified (table 6.14). Various attempts have been made in the past 10 years to coordinate and harmonise policies at an international level. Some analysts consider international cooperation to be the only real means for inducing a market transformation in office equipment. Varone and Aebischer (1999) prefer to keep a diversity of instruments in different countries—an approach that allows for the testing of new instruments, offers the possibility of testing diverse combinations of instruments, and takes advantage of political windows of opportunity specific to each country (as with the Energy Star Program for office equipment in the United States) (Geller, 1995).

Some *developing countries* (China, India) try to follow OECD policies on technical standards and energy labelling. OECD governments should be aware of this implication (box 6.13).

Small and medium-sized companies and public administrations. Small and medium-sized companies and public administrations are typical targets when several policy measures have to be taken simultaneously: professional training, support for initial consulting by external experts, demonstration projects to increase trust in new technical solutions, energy agencies for several tasks (see above), and soft loans. These companies and administrations are also affected by standards for labelling and for cross-cutting technologies such as boilers and electrical motors and drives (Bradbrook, 1992).

This policy mix seems to be successful for this target group in almost all countries. In Russia and most Eastern European countries, energy agencies are responsible for energy efficiency initiatives in end-use sectors. These agencies are playing an important role, supported by energy service companies that provide financial and technical assistance to realise the identified potentials. Brazil and Mexico have also established national agencies for energy efficiency (see box 6.8). With the privatisation of Brazilian utilities, the new concessionaires are required to spend 1 percent of their revenues (less taxes) on energy efficiency, with 0.25 percent specifically for end-use efficiency measures.

Big enterprises and public administrations. Big enterprises and public administrations have specialised staff and energy managers, but they still need specific policy measures to achieve their economic potential. The government of India occasionally uses expert committees to develop policy recommendations. The reports of the committees include several recommendations to encourage energy efficiency improvements (box 6.14). A 'minister's breakfast' is a key tool for motivating top managers of companies and administrations and for raising awareness of energy efficiency potential. In addition, keynote speakers at the annual meetings of industrial associations can help convey positive experiences with new efficient technologies among the responsible middle managers.

Local governments should consider using life-cycle costs and increasing flexibility between investment and operating budgets. This move may require changes in legislation in some countries.

Transportation. Policies on road transportation may include efficiency standards for vehicles imposed by national governments or technical objectives achieved through voluntary agreements among car manufacturers and importers (Bradbrook, 1994). Similar measures can be taken by aeroplane, truck, and bus manufacturers. High fuel

BOX 6.13. FAST TRANSMISSION OF EFFICIENCY PROGRAMMES FROM OECD TO DEVELOPING COUNTRIES: THE CASE OF EFFICIENT LIGHTING

Mexico was the first developing country to implement a large-scale energy-efficient lighting programme for the residential sector. The programme was funded by the Mexican Electricity Commission, ($10 million), the Global Environment Facility ($10 million), and the Norwegian government ($3 million). Between 1995 and 1998 about 1 million compact fluorescent lamps were sold in the areas covered by the programme. Use of the lamps avoided 66.3 megawatts of peak capacity and resulted in monthly energy savings of 30 gigawatt-hours. Given the lifetime of the efficient lamps, the impacts of the programme are expected to last until 2006 (Padilla, 1999).

Economic evaluations show positive returns to households, the power sector, and society. The programme, ILUMEX (Illumination of Mexico), has also helped generate direct and indirect jobs, training and building indigenous capacity to design and implement large-scale efficiency programmes (Vargas Nieto, 1999). Smaller residential energy-efficient lighting programmes have been introduced in other Latin American countries, including Bolivia, Brazil, Costa Rica, Ecuador, and Peru.

TABLE 6.14. POLICIES TO INCREASE EFFICIENCY IN ELECTRIC APPLIANCES AND OFFICE EQUIPMENT, VARIOUS OECD COUNTRIES

Area	Canada	Denmark	Sweden	Switzerland	United States
Household appliances	Mandatory labelling (1978) Standards (1992)	Mandatory labelling (1982) Standards (1994)	Mandatory labelling (1976) Technology procurement (1988)	Negotiated target values (1990) Voluntary labelling (1990)	Voluntary labelling (1973) Negotiated target values (1975) Mandatory labelling (1975) Standards (1978) Technology procurement (1992)
Office equipment				Negotiated target values (1990) Quality labelling (1994) Public purchasing (1994)	Quality labelling (1992) Public purchasing (1993)

Source: Varone 1998, p. 143.

taxes in countries with low taxation may support technical progress. A more systemic view relates to several areas of transport systems and policy measures (IEA, 1997a):

- Subsidies for mobility (such as for daily commuting, national airlines, or public urban transport) increase the demand for transportation, especially road transport, and should be removed where socially acceptable. An untaxed benefit for employees driving a car bought by companies or institutions should also be removed.

BOX 6.14. ENERGY EFFICIENCY POLICY RECOMMENDATIONS BY EXPERT COMMITTEES FOR COMPANIES IN INDIA

Technical and operational measures
- Detailed energy audit should be made mandatory in all large and medium-sized enterprises.
- Potential cogeneration opportunities should be identified and pursued by providing financial assistance
- Energy consumption norms should be set for each industry type and penalties and rewards instituted based on the performance of the industry.

Fiscal and economic measures
- Creation of an energy conservation fund by levying energy conservation taxes on industrial consumption of petroleum products, coal, and electricity.
- Customs duty relief on energy conservation equipment.

Energy pricing
- Energy pricing policies must ensure that sufficient surplus is generated to finance energy sector investments, economical energy use is induced, and interfuel substitution is encouraged.

Industrial licensing, production, and growth
- Before licenses are given to new units, the capacity of existing units and the capacity use factor should be taken into consideration.
- In setting up new units, the technology should be the least energy-intensive option.
- The possibility of using waste heat from power plants by setting up appropriate industries in the vicinity should be considered.

Organisational measures
- The appointment of energy managers in large and medium-sized industries should be mandatory. For small-scale enterprises, a mechanism should be instituted for energy auditing and reporting.

Energy equipment
- Better standards should be set for energy-consuming equipment.
- Restrictions must be placed on the sale of low-efficiency equipment.
- Manufacture of instruments required to monitor energy flows must be encouraged. Imports of such instruments and spare parts should be free of customs duty.

Research and development
- Each industrial process should be reviewed to identify the research and development required to reduce energy consumption.
- Research and development on energy efficiency should be sponsored by the government as a distinct component of the science and technology plan.

Other measures
- Formal training to develop energy conservation expertise should be introduced in technical institutions.
- The government should recognise and honour individuals and organisations for outstanding performance on energy conservation.
- Efforts to raise awareness on energy conservation should be intensified.

Source: Bhattacharjee, 1999.

- Road user charges and parking charges may reduce driving in cities, cut down on congestion and road accidents, and shift some mobility to public transport. Car sharing also has implications for car use and occupancy levels.
- It is possible to lower the cost of public transport through automation and international procurement, as is a better organisation of rail freight crossing national borders.
- In the long term, intelligent city planning that does not divide an urban area by functions and related sections creates substantial potential for reduced mobility.

In *higher-income developing countries* there are concerns that a shift from fuel-efficient to fuel-inefficient transport is threatening the oil security of these countries. To address these concerns, policies should encourage a shift from road transport to subways and rail transport by reducing travel times and increasing the costs of road transportation. These countries should also search for new financing to replace old bus fleets.

Agriculture. Two main issues affect the energy efficiency of agriculture in *developing countries*. The first is related to subsidised electricity tariffs for this sector; the second is the use of highly inefficient prime movers for agricultural pump sets and the ineffective configuration in which they are often used. Increases in electricity tariffs should be accompanied by free consultation by experts and an expansion of credit and savings schemes to help rural people keep their energy costs at an acceptable level. Efficient prime movers and appliances and organisational measures in water use efficiency and irrigation management would help achieve that goal.

Cogeneration. Liberalisation of the electricity market may have different implications for cogeneration in different countries (Jochem and Tönsing, 1998; AGFW, 2000). Earlier obstacles, such as low buyback rates and high rates for maintenance and emergency power, are alleviated by competition. But a legal framework for wheeling and public control seems to be necessary to level the playing field, particularly during the adaptation phase of liberalisation and for small and medium-size cogeneration plants of independent power producers. Lack of expertise and the trend of outsourcing cogeneration plants in industry can be addressed by supporting energy service companies with training, standardised contracts for small units, and deductions on fuels for cogeneration.

Maintaining energy-efficient cogeneration with district heating in *industrialised and transition economies* requires determination, a legal framework, technical and economic skills, and financial resources. Several steps are needed to make or to keep centralised district heating systems competitive:

- A possibility of switching between fuels (lowering gas prices by switching to storable oil in the coldest 100–200 hours of the winter) and using cheap fuel (‘puffer’ gas, coal, municipal solid waste, garbage incineration, sewage treatment biogas).
- Proper and economic sharing of heat generation between centralised heat units and peak load boilers, and an increase in the electricity production planted on the given heat demand by turning to higher parameters in the power-generating cycle (such as combined gas and steam cycles).

- Better performance control of the heating system, variable mass-flow in addition to temperature control in hot water systems, lower temperatures in the heating system, and the use of heat for cooling (through absorption techniques) to improve the seasonal load of the system.
- One-by-one metering and price collection for consumers in transition economies.
- A minimum buyback rate for cogenerated electricity in the adaptation phase of liberalisation (AGFW, 2000).

Such a bundle of measures can assure the competitiveness of other options and the realisation of the huge potential for cogeneration in centralised heating systems.

In *developing countries* a lack of knowledge, capital, and hard currency may constrain cogeneration investments. Thus policy measures and incentives are often needed—and were recommended, for example, by a task force in India in 1993. The Ministry of Non-Conventional Energy Sources launched a national programme promoting bagasse-based cogeneration. The process of agreeing on mutually acceptable buyback rates and wheeling of power by state electricity boards is still under way, but there is hope that the institutional barriers will give way to large-scale cogeneration, particularly in liberalised electricity markets.

The globalisation of many industrial sectors creates enormous potential for improving energy efficiency at the global scale.

International policy measures

The globalisation of many industrial sectors creates enormous potential for improving energy efficiency at the global scale. Harmonising technical standards for manufactured goods offers new opportunities for economies of scale, lowering the cost of energy-efficient products. To avoid the import of energy-inefficient products, governments, associations of importers, and NGOs may consider negotiating efficiency standards for appliances and other mass-produced products imported from industrialised countries. Imported vehicles, used cars, buses, and trucks should not be more than five or six years old (as in Bangladesh and Hungary). Similar rules could be introduced for major imported and energy-intensive plants.

The Energy Charter Protocol on Energy Efficiency and Related Environmental Aspects entered into force in April 1998. The protocol is legally binding but does not impose enforceable obligations on nations to take specified measures. It is a 'soft law' requiring actions such as:

- Formulating aims and strategies for improving energy efficiency and establishing energy efficiency policies.
- Developing, implementing, and updating efficiency programmes and establishing energy efficiency bodies that are sufficiently funded and staffed to develop and implement policies.
- Creating the necessary legal, regulatory, and institutional environment for energy efficiency, with signatories cooperating or assisting each other in this area.

The protocol received significant political support from the EU Environmental Ministers Conference in June 1998. By December 1998, however, it had only about 40 signatories, mainly Western European countries and transition economies. Thus it has no world-wide support (Bradbrook, 1997).

Commitments to the Kyoto Protocol by Annex B countries are a major driver of energy efficiency, as about 70 percent of these countries' greenhouse gas emissions are related to energy use. Although energy efficiency is a major contributor for achieving the targets of the protocol, there are few references to it in the text of the document. Ratification of the protocol and implementation of the flexible instruments will be important for developing policy awareness in industrialised countries of the substantial potential that improved energy efficiency offers for meeting the objectives.

Better air traffic management will likely reduce aviation fuel burn by some 10 percent if fully implemented in the next 20 years—provided the necessary international regulatory and institutional arrangements have been put in place in time. Stringent aircraft engine emission and energy efficiency regulations or voluntary agreements among airlines can expedite technological innovations. Efforts to remove subsidies, impose environmental levies (charges or taxes), and promote emissions trading could be negotiated at the international level (IPCC, 1999b). These economic policies—though generally preferred by industry—may be highly controversial.

Conclusion

As the long-term potential for energy efficiency reduces useful energy demand and the proceeding levels of energy conversion, future energy policy of most countries and on the international level will have to broaden substantially its scope from energy supply to energy services. This kind of policy will be much more demanding in designing target group–specific and technology-specific bundles of policy measures. But the success of this new policy process will be worth the effort from the economic, social and environmental perspective. ■

Notes

1. Lee Schipper was the lead author of this section.
2. Eberhard Jochem was the lead author of this box.
3. Inna Gritsevich and Eberhard Jochem were the lead authors of this section.
4. Anthony Adegbulugbe was the lead author of this section.
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6. Eberhard Jochem was the lead author of this section.
7. Eberhard Jochem was the lead author of this box.
8. Bernard Aebischer and Eberhard Jochem were the lead authors of this section.
9. Ernst Worrell, Allen Chen, Tim McIntosch, and Louise Metirer were the lead authors of this section.
10. This means that the cost-effective potential is probably equivalent to the microeconomic potential (see the introduction to the section on potential economic benefits).

11. The estimates of the economic potential are based on supply curves for each sector developed by Bailie and others (1998). It is unclear what discount rate was used to estimate the economic potential. Hence we cannot determine if the study estimates a microeconomic or macroeconomic potential (see box 6.2).

12. It is unclear what discount rate was used to estimate the economic potential. In some economic assessments in this report a discount rate of 50 percent is used for investments in the transportation sector.

13. Bidyut Baran Saha and David Bonilla were the lead authors of this section.

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27. Eberhard Jochem was the lead author of this section.

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