ENERGY EFFICIENCY AND THE ENVIRONMENT

INTERNATIONAL ENERGY AGENCY

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The International Energy Agency (IEA) is an autonomous body which was established in November 1974 within the framework of the Organisation for Economic Co-operation and Development (OECD) to implement an international energy programme.

It carries out a comprehensive programme of energy co-operation among twenty-one* of the OECD's twenty-four Member countries. The basic aims of the IEA are:

i) co-operation among IEA participating countries to reduce excessive dependence on oil through energy conservation, development of alternative energy sources and energy research and development;

ii) an information system on the international oil market as well as consultation with oil companies;

iii) co-operation with oil producing and other oil consuming countries with a view to developing a stable international energy trade as well as the rational management and use of world energy resources in the interest of all countries;

iv) a plan to prepare Participating Countries against the risk of a major disruption of oil supplies and to share available oil in the event of an emergency.

* *IEA Participating Countries are: Australia, Austria, Belgium, Canada, Denmark, Germany, Greece, Ireland, Italy, Japan, Luxembourg, the Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, United Kingdom, United States. The Commission of the European Communities takes part in the work of the IEA.*

ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

Pursuant to Article 1 of the Convention signed in Paris on 14th December 1960, and which came into force on 30th September 1961, the Organisation for Economic Co-operation and Development (OECD) shall promote policies designed:

— to achieve the highest sustainable economic growth and employment and a rising standard of living in Member countries, while maintaining financial stability, and thus to contribute to the development of the world economy;

— to contribute to sound economic expansion in Member as well as non-member countries in the process of economic development; and

— to contribute to the expansion of world trade on a multilateral, non-discriminatory basis in accordance with international obligations.

The original Member countries of the OECD are Austria, Belgium, Canada, Denmark, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States. The following countries became Members subsequently through accession at the dates indicated hereafter: Japan (28th April 1964), Finland (28th January 1969), Australia (7th June 1971) and New Zealand (29th May 1973). The Commission of the European Communities takes part in the work of the OECD (Article 13 of the OECD Convention). Yugoslavia takes part in some of the work of the OECD (agreement of 28th October 1961).

FOREWORD

Improving energy efficiency continues to be an important component of energy policy. Widespread concern in IEA countries about the environmental impact of energy activities and, more recently, about the threat of global climate change has further emphasised the importance of using energy more efficiently. At their most recent meeting in June 1991, IEA Ministers reaffirmed their strong commitment to integrate policies of sustainable growth, environmental protection and economic growth. Ministers agreed that energy efficiency had made a major contribution in the past to the achievement of these goals and recognised that there is considerable scope for further gains, though numerous barriers exist to realising these gains.

This present study examines the future contribution that improved energy efficiency can realistically be expected to make to achieving energy, economic and environmental objectives, on the basis of the lessons learned from our past experience and the prospects for further efficiency gains. The study focuses on energy use in energy-intensive industries, in buildings and in road transport, which represent over 75% of total final energy use and CO_2 emissions in IEA countries. While it does not attempt to provide an IEA-wide quantification of potential savings and their costs, one of its principal findings is that significant further energy efficiency improvements will be made over the next ten to twenty years as capital stock is replaced by new, more efficient technologies. Even further gains are technically possible using technologies that are available today. Governments have an important role to play in bridging the gap between technical opportunities for improving energy efficiency and the decisions made by consumers in the marketplace.

The study is timely because we are currently facing a changing energy situation where environmental commitments call for effective policy measures and realistic assessments of available policy options. If improved energy efficiency is to make a substantial contribution to reducing emissions of carbon dioxide, policy measures will be necessary. It is therefore essential to improve our knowledge of the costs and benefits of energy efficiency policy measures and of the many technical and market factors that determine energy use in IEA countries. This effort is indispensable in order to develop effective energy efficiency policies that also ensure that the best possible use is made of public and private resources invested in energy efficiency improvements.

The report is published under my responsibility as Executive Director of the IEA and does not necessarily reflect the views or policies of the IEA or its Member governments.

Helga Steeg
Executive Director

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EXECUTIVE SUMMARY

BACKGROUND AND PURPOSE

Over the last 15 years, IEA Member countries have been successful in reducing the amount of energy needed to provide goods and services. Improving the efficiency of energy use is a promising strategy to achieve both energy security and environmental goals, particularly the reduction of carbon dioxide emissions that contribute to global climate change. Earlier IEA studies indicated that there is a considerable technical potential for energy efficiency improvements. Nevertheless, the actual effectiveness and costs of energy efficiency measures need to be better understood and the lack of information in this area needs to be addressed. Consequently, the IEA undertook this study to evaluate the scope for further energy efficiency improvements in Member countries, the measures that can accelerate such improvements and their environmental and economic effects.

By reviewing past energy efficiency developments and policies, a clearer sense of the future scope for energy efficiency is obtained. The study does not provide an IEA-wide quantification of the potential for further energy efficiency improvements and their costs. While some national studies have been completed which provide such estimates, many more would be necessary to give a complete picture of the situation in the IEA as a whole. Therefore, though IEA-wide estimates could be attempted, they would be highly theoretical and of limited use. What this study does examine in detail is the technical and market factors that are likely to determine the cost-effectiveness of energy efficiency improvements in a range of end-use sectors. In addition, on the basis of available country-specific studies of the scope and costs of energy efficient strategies, it is possible to assess the macroeconomic impact of measures designed to accelerate the penetration of energy efficient technologies. Finally, the study points to areas for further work, particularly in the terms of improved data and information on energy use and on the cost-effectiveness of energy efficiency investments.

ENERGY END-USES AND EMISSIONS OF CO_2

The most immediate and direct environmental benefit of improving the efficiency of energy use is a reduction in the use of resources and in the emission of many air pollutants, as well as of CO_2. This benefit is best evaluated if emissions that occur upstream in the fuel cycles, in the production, transformation and transport of energy, are taken into account at end-use level. Such an approach is essential to a full understanding of the environmental benefits of energy efficiency improvements.

Four main features of the energy sector of Member countries have a strong influence on the relative contribution of end-use sectors to total CO_2 emissions: the size and structure of the industrial sector, the importance of road transport and its consequent oil consumption, the share of fossil fuels in electricity generation and the mix of fuels used to heat buildings. Where industry is dominated by energy-intensive production such as iron and steel, this sector is usually the largest contributor to national CO_2 emissions, ahead of the residential and commercial sector. Road transport is absorbing a growing share of oil consumption and is, as a result, an increasingly large contributor to CO_2 emissions. The fuel mix used for electricity generation is also a decisive factor in determining sectoral emission levels. In Member countries where non-fossil energy sources (hydro or nuclear energy) account for a large share of electricity production, transport fuels and heat used in buildings and for industrial processes are major areas where energy efficiency improvements would produce significant CO_2 reductions. In other countries, and particularly those that rely heavily on coal for electricity generation, large benefits can be expected from electricity end-use efficiency, particularly in the residential and commercial sectors, and in industry.

Target areas that are currently large contributors to CO_2 emissions in most IEA Member countries include road transport, energy use in the residential and commercial sector (mainly electric appliances, heating, cooling and lighting) and energy-intensive industries. These sectors are responsible for over 75% of total energy-related CO_2 emissions from IEA Member countries and are also major sources of air pollutants such as SO_2, CO and NO_x.

ENERGY DEMAND AND EFFICIENCY TRENDS

Substantial reductions in oil consumption occurred after the oil price hikes of 1973 and 1979. The rapid increase in oil prices triggered technical improvements in energy efficiency that are still being felt as new, more efficient equipment replaces the existing stock. Annual energy demand increased by less than 1% between 1973 and 1988. Since the mid-1980s, price signals have weakened and economic growth has been stronger. The aggregate GDP of IEA countries grew by 3.6% per year between 1985 and 1988. These developments are reflected in a stronger overall increase in energy demand of 2.4% per year during this period. The largest increase in energy demand occurred in the transport sector (4% per year). Energy demand in the commercial and public service sectors, as well as in industry, grew by 2-3% per year. Compared to these trends, the growth of energy demand in the residential sector was rather modest: less than 1% per year.

The fuel mix used in industry and in the residential and commercial sector has changed substantially over the last 15 years, the most significant feature being a fall in the share of oil and an increase in electricity use. For instance, in the residential and commercial sector, the share of electricity expanded from 21% to 33% of total energy demand between 1973 and 1988. By contrast, the fuel mix of the road transport sector has remained unchanged though there has been an increase in the use of diesel from 14.5% to 26% of oil consumption for road transport.

These developments are clearly evident in changes in energy intensity, defined as the ratio of total primary energy requirements to GDP. The period 1980 to 1984 saw the greatest improvement in energy intensity, which declined by 2.6% per year. Intensity declined by only 1.4% per year between 1984 and 1988. Changes in energy intensity are the result of the combined effects of economic and industrial structural changes, fuel substitution and energy efficiency improvements. Shifts in industrial activity since 1973 have generally reduced the weight of energy-intensive industries in energy demand and therefore contributed to reducing energy intensity. By contrast, structural changes in road transport and in buildings have tended to compensate for reductions in energy intensity due to efficiency improvements. In the residential and commercial sector, the effect of the significant improvements in the efficiency of energy-using equipment observed since 1973 have been offset by their increased use, especially in the case of electric appliances in the residential sector and air conditioning in the commercial sector. In road transport, massive growth in both fleets and traffic have outweighed improvements in the specific consumption of vehicles. In addition, recent trends towards larger and more powerful vehicles are reducing the impact of earlier improvements in fuel economy.

Nevertheless, IEA Member countries have been successful in improving the overall efficiency of their economies. Clearly, changes in energy prices in the 1970s and 1980s were instrumental in this success, though other factors, such as economic growth and technical change, as well as the widespread use of financial instruments and regulatory policy measures in the 1970s and early 1980s, were at work as well.

THE SCOPE FOR FURTHER ENERGY EFFICIENCY IMPROVEMENTS

In virtually all sectors and for all major end-uses, the improvement in energy efficiency observed over the last 15 years is set to continue because the efficiency of new equipment available on the market is usually higher than that of the average stock in use. Past and current improvements in the efficiency of energy-using equipment, ranging from passenger cars to domestic appliances, have yet to be fully felt. Economic growth can play a major part not only in accelerating the rate of turnover of existing equipment, but also in sustaining the technological creativity of industry that fuels the development of energy efficiency.

There is a large technical potential for further improvement in technologies that are readily available but are as yet little used for a variety of reasons, mostly relating to market conditions and consumer behaviour. Additional improvements can be achieved in the longer term, using advanced technologies that are expected to be commercially available and cost-competitive in the near future. Continued energy efficiency R&D shows significant promise to provide even more efficient technologies in the future, though cost constraints may limit the scope of these technologies. For end-uses such as refrigeration and lighting in the residential and commercial sector, improvements of 30-70% are technically possible, with a somewhat lower potential for space conditioning and water heating, though improvements in the building shell of new buildings show substantial promise. Technical changes could also contribute to significant improvements in the fuel economy of road transport vehicles, of the order of 15%, though going beyond this figure to as much as 30-50% would require modifications in vehicle attributes. Technological improvements are also possible in a variety of industrial processes and for a range of cross-cutting industrial technologies, though their potential varies on a case-by-case basis. For instance, the use of industrial motor systems can be improved to achieve 30% savings compared to current levels. However, in some countries, the technical potential for further efficiency improvements in some energy-intensive industries is probably lower than in other end-use sectors, because energy costs represent a large share of production costs in these industries and major efforts have already been made to improve their efficiency.

The scope for further energy efficiency improvements depends not only on technical possibilities to improve energy efficiency, but also on market conditions for the introduction of more energy-efficient technologies. Table 1 puts some of these opportunities into perspective by comparing them with the share of energy use concerned and the degree of market and institutional barriers which need to be overcome. These examples account for nearly 70% of total final energy consumption and over 72% of energy-related CO_2 emissions in IEA countries.

A great deal more work is needed on the cost-effectiveness of the investments necessary to implement these energy efficiency opportunities. Where cost data are available, the cost-benefit analysis is country-specific because energy prices differ from one IEA country to the next and because the price of energy-efficient equipment is also variable. The evaluation of the cost-effectiveness of energy efficiency investments also differs significantly according to the end-use sector concerned. A broader range of case studies than is currently available is needed in order to provide meaningful IEA-wide cost-benefit analysis.

It is also necessary to gain a better understanding than we have of the factors that influence the way consumers perceive energy costs and benefits. These factors are central to any assessment of the market conditions for energy efficiency improvements. In some cases, though no additional equipment costs and relatively limited transaction costs are involved to achieve energy efficiency improvements, these savings are not being made. Many energy efficiency opportunities available today would in fact be already taken up by energy users, if a range of technical and institutional barriers were overcome.

Barriers to the introduction of energy-efficient technologies are probably strongest in the residential sector, where consumers are least responsive to the cost and benefits of energy use. This is related to facts that have been recognised for many years, namely that energy is not adequately metered in large sections of the residential sector and that investment decisions are often split between tenants, owners and contractors. In addition, residential energy users do not usually have easy access to, and do not try to obtain, the necessary technical information and capital. Private transport suffers from many of the same barriers as the residential sector, and the fuel economy of a passenger car is usually not the most important criterion in purchase decisions. Market barriers tend to be less marked in the commercial sector and are lowest in the industrial sector, because these sectors operate in a productive environment where awareness of costs and benefits is important. Indeed, the industrial sector, and especially energy-intensive industries, have in the past substantially improved their energy efficiency, particularly when economic growth has encouraged rapid stock turnover and the introduction of new, more efficient technologies. Nevertheless, energy costs do not always represent a significant share of production costs, required rates of return for energy efficiency are usually very high and industry is not necessarily aware of the positive effect of energy efficiency investments.

Access to technical and economic information and to capital are crucial in the achievement of further energy savings. Governments have a major role to play in removing these barriers and bridging the gap between technical opportunities and the decisions made by individual consumers in the marketplace. The cost of any policy measures should nevertheless be fully assessed and incorporated into an overall analysis of the costs and benefits of energy efficiency investments.

POLICY INSTRUMENTS FOR IMPROVING ENERGY EFFICIENCY

All IEA countries have in the past taken measures to support the improvement in the energy efficiency of their economies, though they have chosen different approaches, with different degrees of success. These measures include information, regulation, price setting and taxation, economic incentives and support for research and development. The degree of effectiveness and the overall cost of each policy measure vary according to country-specific circumstances, such as climate, resource endowment, energy price levels and economic activity. Those responsible for running energy efficiency programmes have often found it difficult to establish clear cause and effect relationships, i.e. to attribute certain energy demand reductions to price effects or to a specific policy measure, and programmes have not always been fully or adequately evaluated. This evaluation can provide essential information to governments that need to know with some assurance the effectiveness of policy measures aimed at improving energy efficiency and implemented to meet commitments to reduce emissions of CO_2.

Information programmes help narrow the gap between technical potential for energy efficiency and current efficiency levels by providing consumers with the technical and economic information they need to make decisions to reduce energy consumption. Nevertheless, information activities play an essentially supportive role in energy efficiency strategies and are most effective when they promote actions that make good sense for the consumer.

Regulations have been mainly limited to thermal standards in the buildings sector, where they appear to have been very effective in reducing energy needs in new buildings. There is considerable scope for further regulatory action for energy efficiency. For instance, vehicle fuel efficiency standards have so far been applied only in the United States, where energy prices are relatively low. For such action to be effective at an international level, it would need to be carefully co-ordinated and planned with manufacturers and consumers. In particular, the costs of regulations for all parties involved should be fully assessed and any potential trade implications examined to avoid trade distortions.

Pricing is certainly one of the most important instruments of energy policy. Energy prices obviously play an essential part in determining energy use. Energy efficiency investments depend on the decisions of thousands of institutions and millions of individuals. These decisions cannot be taken centrally, though they will respond to the play of market forces and in particular to energy prices sending signals to invest in supply capacity and in end-use efficiency. As a result, all IEA countries have increasingly sought to get energy prices onto a more economic basis and remove market distortions. At the very least, governments should ensure that where there is a world market, as for oil, consumer prices should reflect the world market price and where there is no world market, as in the case of electricity, prices should reflect the marginal costs of supply. Governments can also provide an appropriate regulatory framework in the case of electricity and gas at the end-use level and allow prices to approach long-term costs of supply. Energy prices should also internalise as far as possible certain externalities such as the environmental costs of energy production and use — the polluter pays principle.

Taxation is another instrument that can influence consumer behaviour without regulating individual choice. All IEA countries apply taxes or levies to a certain extent, primarily for fiscal reasons. Tax differentials on energy products have been mainly used in the transport sector, between gasoline and diesel. Primarily as result of concern about climate change and in recognition of the relationship between energy prices and demand, several European countries have implemented or are considering increases in existing taxes on certain forms of energy or the introduction of new energy taxes (environmental taxes such as carbon taxes and/or revenue-neutral taxes aimed at reducing energy use and emissions). The emerging consensus is that for any carbon tax to be effective in reducing long-term concentrations of CO_2 in the atmosphere, it would have to be very substantial in both the short and the long term, geographically widespread and applied across the spectrum of carbon-based fuels.

Some governments have supported energy conservation through financial inducements, such as grants, low interest loans, or tax deductions. Experience with past programmes has shown that such activities can, unless they are properly targeted, be very expensive and can result in a misallocation of limited public resources. On the other hand, there are clear indications that these financial support schemes have promoted investments in energy-efficient technologies and have accelerated process innovation. The removal of these programmes has probably enhanced the negative effect of falling energy prices. Financial incentives provided for pollution control and investments that reduced pollutant emissions have not always supported energy-efficient technologies, though more emphasis is now being put on the development of clean energy technologies.

New approaches, such as third-party financing, can help consumers invest in energy efficiency improvements without straining public resources. More recently in some countries, energy suppliers, and particularly electric utilities, have invested in energy efficiency improvements through demand-side initiatives as an alternative to capacity expansion or in response to regulatory pressure. While the impacts of such initiatives on energy demand and their economic consequences have yet to be comprehensively evaluated, the magnitude of recent programmes points to larger achievements in the future, not only in North America, but also in other IEA countries.

All IEA governments have contributed to stimulating the development of new, more energy-efficient technologies by setting long-term priorities and providing financial support for research, development and demonstration programmes. These efforts have involved a very wide range of technologies and the fruits of this research have made and still are making an important contribution to improvements in the efficiency of energy use.

CONCLUSIONS

Past improvements in energy efficiency have played a significant part in limiting CO_2 emissions, along with reductions in the carbon intensity of the energy sector of IEA Member countries. Without the 25% decline in energy intensity that has occurred since 1973, IEA countries would have emitted about 19% more CO_2 than they did in 1988. Though the realistic potential for energy efficiency improvements appears to be promising in many end-use sectors, the relationship between improvements in energy efficiency on the one hand and energy demand and CO_2 emission levels on the other is not a straightforward one. In the past, reductions in energy demand related to energy efficiency improvements have often been compensated by the effect of other factors. The future role of energy efficiency in emission reduction strategies depends on the extent to which efficiency improvements are actually translated into energy demand and emission reductions by consumer behaviour.

A number of policy measures would be necessary in order to ensure that energy efficiency improvements will contribute fully to reducing energy demand and related pollutant emissions. These policy measures, such as energy taxes or regulations, entail costs to the private sector as well as to the public sector. The costs of these policy measures, though they are sometimes hidden, should not be underestimated and need to be carefully assessed. Depending on their scale and nature, they can have a significant macroeconomic effect, on economic growth in particular. More work is required on the costs of energy efficiency improvements and how they are perceived by energy consumers.

While it is possible to carry out theoretical projections of the potential for energy efficiency improvements at a national or regional level, this belies the reality that reliable information on energy demand and efficiency and a better understanding of the many non-technical factors, including the evaluation of cost-effectiveness, that influence energy use are areas of relative weakness in many IEA countries. In many cases, this sort of information can only be provided by extensive, regular surveying. Allocation of budget and staff to these tasks has not always been a priority. Indeed, it appears that detailed data on the way energy is used to provide services and goods are often unavailable and that as a result, stronger cause and effect relationships cannot be fully accessed. This lack of information is an area of serious concern, at a time when it is becoming clear that energy efficiency has a major role to play in achieving environmental goals and in particular, in policies that contribute to limiting climate change.

Table 1

Energy Efficiency Potential: Summary of Opportunities and Barriers

	(A) Estimated Share of Total Final Consumption	(B) Estimated Share of Total CO_2 Emissions	(C) Total Energy Savings Possible[1]	(D) Existing Market/Inst. Barriers[2]	(E) Potential Energy Savings Not Likely to be Achieved[3]
Residential Space Heating and Conditioning	11.4%	11%	10-50%	Some/Many	Mixed
Residential Water Heating	3.4%	3.6%	Mixed	Some/Many	Mixed
Residential Refrigeration	1.1%	2.1%	30-50%	Many	10-30%
Residential Lighting	0.6%	1.2%	over 50%	Many	30-50%
Commercial Space Heating and Conditioning	6.1%	6.8%	Mixed	Some/Many	Mixed
Commercial Lighting	1.5%	3.4%	10-30%	Some/Many	Mixed
Industrial Motors	4.5%	9.0%	10-30%	Few/Some	0-10%
Steel	4.1%	4.6%	15-25%	Few/Some	0-15%
Chemicals	8.4%	5.9%	10-25%	Few/Some	0-20%
Pulp and Paper	2.9%	1.2%	10-30%	Few/Some	0-10%
Cement	0.1%	0.9%[4]	10-40%	Few/Some	0-10%
Passengers Cars	15.2%	13.7%	30-50%	Many	20-30%
Goods Vehicles	10.1%	9.1%	20-40%	Some	10-20%

How to read this table: For example, for lighting, over 50% per unit savings would result if the best available technology were used to replace the average lighting stock in use today over the next ten to twenty years. Some of these savings would take place under existing market and policy conditions. But due to the many market and institutional barriers, there would remain a 30-50% potential for savings that would not be achieved.

1. Based on a comparison of the average efficiency of existing capital stocks to the efficiency of the best available new technology. This estimate includes the savings likely to be achieved in response to current market forces and government policies as well as those potential savings (indicated in Column E) not likely to be achieved by current efforts.

2. Extent of existing market and institutional barriers to efficiency investments.

3. Potential savings (reductions per unit) not likely to be achieved in response to current market forces and government policies (part of total indicated in Column C).

4. Energy use only.

CHAPTER I

INTRODUCTION

1. BACKGROUND AND MAJOR OBJECTIVES

Energy efficiency policy measures have contributed in the past to the improvement of the energy security of IEA Member countries. However, recent shifts in the factors influencing the role of improved energy efficiency, particularly in relation to the environment, have become apparent. Environmental considerations are increasingly influencing energy policy, and recent concerns about climate change are further emphasising the orientation of policies towards environmental goals. Energy activities are either contributing factors in or the main causes of a significant number of environmental concerns. Major energy-related issues include global climate change, acid deposition and urban air quality. Energy use, especially fuel combustion, which generates a significant share of anthropogenic emissions of CO_2, SO_2 and NO_x, is at the centre of a number of environmental problems that are today (and in certain cases have been for some time) considered as requiring urgent attention. It is common knowledge that reduced energy demand could also reduce the related burden on the environment. In particular for the climate change issue, more efficient use of the fuels that emit greenhouse gases seems to be a promising response strategy (IEA, 1990d).

Past improvements in efficiency have either had very beneficial effects on the environment, or at least offset significant degradation that would have resulted from further growth in energy demand. But it is not known how individual factors influence energy demand, what realistic scope for further energy efficiency improvements exists throughout the IEA and what role such improvements could play in reducing the pressure of energy activities on the environment.

An improvement in energy efficiency is regarded as any action undertaken by a producer or a consumer of energy products that reduces energy use per unit of output, without affecting the level of service provided. Energy efficiency improvements can therefore be considered at all stages of the various fuel cycles. Greater energy efficiency can be brought about through hardware improvements, such as technological enhancements; software changes, such as improved energy management and better operational practices; or a combination of both.

The major objectives of the study are:

- drawing on existing data on emission factors, to identify the relative contributions of various end-use sectors to the generation of polluting emissions, with major emphasis on greenhouse gases, and to select the major subsectors that should be analysed in detail;

- to evaluate the extent and nature of further opportunities for energy efficiency improvements by focusing on selected major end-uses;

- to identify and examine effective policies for achieving the potential for efficiency improvements in these end-uses;

- to assess the possible impact of resulting demand reductions on the emission of greenhouse gases and, secondarily, of other pollutants, and on economic costs.

The basic time frame for the study is up to 2005, extended to 2020 — as far as available information permits — for more speculative analysis concerning technological developments.

2. SCOPE OF THE STUDY

Obvious benefits can result from a reduction in energy input requirements per unit of output, which in turn generally reduces the quantity of pollutants generated per unit of useful work. The absolute environmental benefits derived in this manner from greater energy efficiency vary with the type of energy being saved (as pollutants vary by energy source), the extent of the efficiency gain and the nature of the energy process. Most importantly, the improvement in pollution varies according to the pollutant considered. The emission levels of some pollutants vary with the amount of energy used. This is the case, for instance, with CO_2 and SO_2 . For other pollutants, such as NO_x, CO or VOC, the relationship between emission levels and the amount of energy used is not linear and depends essentially on the technology applied. In some cases, though less energy may be used (for instance, to travel a given distance), the production of pollutants may be higher.

Energy efficiency improvements may be made not only in the end use of energy but also in the production of primary energy resources or the transformation to intermediate or final energy forms. In addition to this relatively straightforward view of the role of energy efficiency, it is necessary to adopt a fuel cycle perspective in order to understand the real implications of energy use, which should take into account the environmental impact of related activities such as energy production, transport and transformation. Most energy efficiency improvements can usually generate secondary benefits through the effect that reduced energy use has on the environmental impact of the whole fuel cycle and, ultimately, on the energy system as a whole. By reducing the need for certain related activities, improved energy efficiency can have a strong cumulative effect on the overall volume of energy activities and therefore on any environmental degradation they might entail. For instance, energy-efficient measures can delay the need to develop new energy resources and sites for transportation and conversion facilities.

This study does not attempt to quantify all the indirect environmental benefits of improved energy efficiency, though they should of course be kept in mind. The study concentrates on the direct benefits of improved end-use efficiency, which are essentially related to the reduction of air pollution. CO_2 is the primary focus of the study, though other greenhouse gases and SO_2 are included where data permit. It should also be noted that energy efficiency improvements have not always been completely benign environmentally, though the study will not focus on these effects, as in almost every case corrective actions have been possible and better planning, design, material selection and siting can reduce or eliminate negative effects in new efforts.

3. PRESENTATION OF THE STUDY

Chapter II provides the main background to the study by presenting an analysis of the contribution of energy end-uses to the generation of major pollutants. IEA and national CO_2 emissions in 1988 are estimated on the basis of delivered energy emission factors and energy figures from IEA: *Energy Balances of OECD Countries*. Some subsectoral detail is presented using other sources of energy data. Key sectors and end-uses in terms of energy demand reduction and emission reduction are shown to be: energy-intensive industry, road transport, and electricity and heat in buildings. Chapter III reviews historical developments in energy demand and efficiency in these sectors. This review is the basis of an assessment of the potential for improved efficiency, presented in Chapter IV. Possible energy savings are first evaluated in terms of their technical potential. The assessment of their market potential takes into account barriers that might hinder the introduction of more energy-efficient technologies. Equipment costs and their perception by energy users are also discussed in terms of the possible cost-effectiveness of these energy efficiency improvements. Chapter V contains an identification and an assessment of energy efficiency policies and instruments, both traditional and innovative. Their capacity to support the introduction of energy-efficient technologies and processes is discussed and evaluated in terms of possible energy savings and emission reductions. The costs of these policy measures are examined for both the public and private sectors, and their possible effects on macro-economic, energy security and other goals are explored. Chapter VI summarises the findings of the study and presents conclusions and areas for further work for the development of effective policy options for improved energy efficiency and environmental protection.

CHAPTER II

CONTRIBUTION OF END-USES TO THE GENERATION OF MAJOR POLLUTANTS

1. IDENTIFICATION OF THE DISTRIBUTION OF END-USE EMISSIONS

In order to better assess the role that energy efficiency improvements can play in reducing emissions of major pollutants, the link between energy activities and pollutant generation needs to be explored in detail from an end-use perspective. The distribution of pollutant emissions among the various end-use sectors varies from country to country according to the structure of supply and demand, and the fuel mix. Hence the analysis of the relative contributions of end-use sectors to the generation of major pollutants needs to be country-specific and sector-specific. In addition, the new perspective that environmental objectives are providing energy efficiency efforts calls for in-depth methodological work in order to provide a consistent picture of the contributions of various energy end-uses to the generation of pollutants across Member countries.

1.1 Methodology and data

In a first stage of the analysis, as many end-use sectors and subsectors as possible are included, within the limitations of the data available. The calculations presented here concern mainly emissions of CO_2 , which is the most important energy-related greenhouse gas and which is most likely to be directly affected by energy efficiency improvements, as it is fuel-dependent. To calculate end-use-related CO_2 emissions, energy consumption data are multiplied by carbon emission coefficients. The sources of energy consumption figures and of emission coefficients are presented below.

(a) energy data sources

IEA: *Energy Balances of OECD Countries* (1990a) have been used to provide aggregate and national energy data for 1988. The fuel categories considered in the Energy Balances are: coal, other solid fuels, oil and gas. In addition to providing total primary energy requirements (TPER), inputs to electricity generation, and losses and transformation, the Energy Balances give total final energy consumption (TFC) data broken down into the following sectors: industry, transport and others. Some further subsectoral breakdown is available in IEA: *Energy Balances of OECD Countries*, such as industrial branches, air, road, rail and water transport, agriculture, and the commercial, residential and public sectors.

It is necessary to use sources other than IEA: *Energy Balances of OECD Countries* to obtain other subsectoral breakdowns (e.g. passenger cars, light vehicles) or breakdown by end-use (e.g. lighting, heating), particularly in the transport and buildings sectors. However, this further level of detail is not available for all Member countries. In addition, the breakdown by fuel is not always possible. For instance, coal in the residential sector can be assumed to be entirely destined for space and water heating purposes. But the same is not true of gas, which can also be used for cooking. More detailed analysis based on the use of diverse data sources has been reserved for the key end-uses and subsectors listed at the end of this chapter.

(b) calculation of emission factors

A full comparison of emissions by end-use should involve some estimation of indirect emissions, which can occur at the front end of the fuel cycle in the production, storage and distribution of the final product. For example, gasoline production involves emissions of greenhouse gases at the well-head during crude oil production, during refining and during storage and distribution. In the case of natural gas, the situation is simpler, as indirect emissions occur mainly through leakage during distribution. Only some of these indirect emissions have been quantified, and these are usually estimates that are subject to considerable uncertainty. Mainly for this reason, only indirect emissions that occur during fuel processing have been included in estimates of emissions generated by the end-use (i.e. combustion of fuels). This is consistent with the decision to consider only the direct benefits of any improvements in energy efficiency at end-use level.

For fossil fuels, it is reasonable to assume that the bulk of the consumption due to transformation is of the same type as the fuel itself; this "parasitic" energy use can simply be assumed to be attributable to final consumption of the same fuel. This assumption breaks down in the case of electricity. Emissions related to electricity use do not occur at the end-use level. The treatment of electricity in an end-use approach to emissions therefore requires some clarification. It is reasonable to assume that improvements in the end-use efficiency of electricity, for instance for lighting or electric motors, will have a cumulative effect on the need to generate electricity at the power station level and will therefore reduce emissions from the combustion of fossil fuels to produce electricity. The effect of improvements in electricity end-use efficiency needs to be taken into account, even if this involves some simplification. An estimate is therefore provided of the contribution that electricity end-uses indirectly make to the generation of emissions.

Three main stages of calculation are carried out to estimate CO_2 emissions related to end-uses of energy and to include major emissions occurring at previous stages of the fuel cycle.

As indicated above, some simplification is necessary, if only because of data limitations. In this analysis, particular attention has been paid to upstream energy consumption/carbon emissions related to:

- energy transformation and losses;
- electricity generation.

Any decrease in the amount of energy available due to consumption or losses along the fuel cycle is compensated by a proportional increase in the emission factor applied. Two types of energy emission factors have therefore been calculated: primary and delivered, the latter including delivered fuels emission factors and delivered electricity emission factors. It is the CO_2 emissions calculated using delivered energy emission factors that are most relevant to assessments of policy responses, whether the focus is upon energy efficiency measures or upon fuel substitution. Emissions of CO_2 are expressed in millions of metric tons (Mt) of carbon and emission factors are expressed in Mt carbon/Mtoe.

Identification of primary energy emission factors: The starting point is the application of primary factors, which show how much carbon is produced by the combustion of four types of primary energy. These factors are taken from the OECD-IEA study *Greenhouse Gas Emissions: The Energy Dimension* (OECD/IEA, 1991). They are based on the carbon content of fuels using a given heat value, in this case the lower net calorific value used in IEA: *Energy Balances of OECD Countries*. A single set of average emission factors, using the assumptions on carbon content and heat value from this study, has been applied to the four categories of primary energy data. These primary energy emission factors are presented in Table II.1, for the OECD as a whole.

Table II.1
Primary Energy Emission Factors
(in Mt carbon/Mtoe)

Coal	1.09
Other solid fuels	0.89
Oil	0.84
Gas	0.64

Each fuel's emission factor is assumed to remain constant within the OECD, except in the case of coal. More precise estimates of the emissions associated with different types of coal and the national market share of each type have been found for only a few countries. In the absence of reliable estimates for each Member country, in order to avoid any distortion of the data base, average regional figures have been used for OECD Europe (1.11 Mt carbon/Mtoe), North America (1.08 Mt carbon/Mtoe) and the Pacific (1.10 Mt carbon/Mtoe).

Calculation of delivered energy emission factors: In order to account for the energy expenditure and related emissions due to losses and transformation, primary energy emission factors need to be adjusted before they are applied to delivered fuels. The delivered fuel emission factor for each of the four fuel types is calculated as follows:

- delivered fuel emission factor = emissions from primary energy requirements / delivered fuel

Average delivered fuel emission factors for the IEA in 1988 are shown in Table II.2.

Table II.2
Delivered Fuel Emission Factors
(in Mt carbon/Mtoe)

Coal	1.14
Other solid fuels	0.89
Oil	0.89
Gas	0.73

Calculation of delivered electricity emission factors: This stage of the analysis concerns only electricity. It aims to provide an aggregate figure for emissions that can be related to all end-uses of electricity and that therefore accounts for emissions at the power plant as well as those that can be related to electricity losses. It should reflect the fuel mix used to generate electricity, and particularly the importance of fossil fuels relative to other generation sources. It is therefore a matter of calculating an emission factor that will correspond to the *average* emission related to an Mtoe of electricity used. This can be achieved by dividing total emissions produced by the generation of electricity by the amount of electricity delivered. The delivered electricity emission factor is calculated as follows:

- delivered electricity emission factor = emissions from electricity generation / delivered electricity

For the IEA as a whole in 1988, the average delivered electricity emission factor is 1.96 Mt carbon/Mtoe delivered electricity.

Delivered energy (fuel and electricity) emission factors vary according to the fuel mix and the share of losses and transformation in the energy balance. They therefore need to be calculated on a country-specific basis for each year. In addition, the relationship between changes in electricity demand and electricity generation emission is not linear, because of the different use of the various energy sources in the fuel mix for baseload versus peak generation. For instance, gas is often used for peak generation and coal for baseload, with different levels of CO_2 emissions. Depending on the load curve, reductions in electricity end-use will therefore have very different effects in terms of emissions from generation. Further refinements taking these considerations into account are possible, but for practical reasons the long-term view that reductions in electricity end-use will affect the average emissions from the electricity generating sector has been taken in this analysis. Further detail can also be considered in the case of different emission factors, not only for the four main fuel types considered here, but also for different end-use products within these categories, such as gasoline or diesel for the transport sector.

(c) calculation of CO_2 emissions

Primary energy emission factors are applicable to TPER figures (which in IEA: *Energy Balances of OECD Countries* exclude international bunkers), minus non-energy uses and petrochemical feedstocks, for the four categories of fuel. Multiplying these figures by the relevant fuel emission factor provides a first picture of the amount of carbon produced by primary energy requirements.

Energy expenditure relating to losses and transformation includes statistical differences. Non-energy uses and petrochemical feedstocks are excluded from end-use calculations, but their share in losses and transformation is difficult to isolate and is therefore still included in those figures.

Delivered fuel emission factors are applicable to TFC figures for the four categories of fuel, as well as to further sectoral and subsectoral end-use consumption. They can also be applied to fuel inputs to electricity generation, which includes utilities and autoproducers. Delivered electricity emission factors are applicable to TFC of electricity, as well as to sectoral electricity consumption figures. No separate treatment has been given to electricity imports or exports, because these items pose particular problems as emissions at the power plant are separated from end-uses by international trade, which is difficult to trace with precision. Emission allocation is therefore impossible in practice. In addition, as a large part of internationally traded electricity is hydropower or nuclear energy, its direct contribution to carbon emissions need not be taken into consideration.

Heat produced through combined heat and power (CHP, or co-generation) cannot be traced to a single combustion source and it is therefore impossible to ascribe an emission factor to the energy produced and used. This limitation is mitigated by the fact that heat from CHP installations can be considered a by-product of electricity generation, for which overall emissions due to combustion have already been taken into account. It is therefore possible to consider that no extra emissions are produced by the heat recovered in this process. Heat distributed through district heating networks poses similar allocation problems among various end-use sectors. IEA: *Energy Balances of OECD Countries* indicate that this heat is already included in industry or other sectoral consumption. As a result, no attempt has been made to isolate related emissions.

A further limitation of the data contained in IEA: *Energy Balances of OECD Countries* can in some cases result in an increase in the delivered gas emission factor. In many fields gas is associated, and produced in combination, with oil. Some of this gas is used in the production and transport process (electricity generation on production platforms, pipeline compression, etc). The gas used for these purposes is often allocated to gas rather than oil production in energy balances. As a result, corresponding emissions are included in the delivered fuel emission factor for gas and the resulting figure is higher than it should be. It is not possible at present to improve the separation of gas used by the gas industry and that used by the oil industry.

1.2 CO_2 emissions by end-use sector and major subsector

CO_2 emissions from TPER, electricity generation, TFC and major sectors and subsectors are presented in Annex 1 for the IEA as a whole and for each Member country. Primary and delivered energy emission factors are also indicated in each case. Total emissions calculated for TPER and for TFC are equivalent, except in the case of Norway, where total emissions for TFC are 13% lower than for TPER. This is because emissions from exported gas and gas used in the oil and gas production and transformation industry cannot be attributed to electricity generation or end-uses and thus do not appear in TFC emission figures. Delivered energy emission factors should be higher than primary energy emission factors, as they include the effects of energy transformation and losses. Nevertheless, this may not be the case when energy transformation involves a change from one fuel to another, as from gas to synfuel in New Zealand or from coal to gas in Japan.

Table II.3 summarises the contribution of end-use sectors to the generation of CO_2 ; emissions from each energy use are expressed as a percentage of total national emissions. An indication of the relative "carbon intensity" of electricity generation is provided by the delivered electricity emission factor: the higher the factor, the greater the amount of carbon-intensive fuels used in the generation mix. In the same way, the overall carbon intensity of each country can be estimated by dividing total carbon emissions by TFC.

In the IEA as a whole, industry and other sectors play a similar part in total emissions (34-38%) and transport contributes the remaining 28%. Though there are marked differences among Member countries, the following preliminary points can be made on the relative importance of end-use sectors:

- the carbon intensity of electricity production has a strong effect on the relative shares of end-use sectors: In countries with a lower carbon intensity for electricity generation (below 1), transport is generally a major source of CO_2 emissions, typically contributing over 30% of total emissions;
- in the same way, in countries where electricity generation is carbon-intensive, the residential and commercial sectors make larger contributions to CO_2 emissions, especially in countries with high levels of electricity use in these sectors:
- the share of industry varies from as little as 15% (Switzerland) to as much as 59% (Luxembourg) and seems to be more independent than other sectors from the situation of the electricity generation sector. The initial share of industry in the energy balance, the structure of the industrial sector and the choice of industrial fuels (particularly gas or coal) have a significant impact on the final share of the sector in total CO_2 emissions.

1.3 Detailed CO_2 emissions from subsectors and end-uses

On the basis of the CO_2 emission data provided in Annex 1, it is possible to present more detailed CO_2 emission estimates according to major subsectors in the industrial, transport and other sectors, as summarised in the figures below for the IEA as a whole.

Table II.3

Share of End-Use Sectors in CO_2 Emissions[1] (1988)

	% Share of CO_2 emissions			Carbon intensity[2]	
	Industry	Transport	Other	Electricity	Total
IEA	34.1	28.1	37.8	1.96	1.07
Australia	40.4	27.1	32.5	3.35	1.35
Austria	31.0	328.2	40.8	0.71	0.86
Belgium	39.5	24.0	36.5	1.17	0.94
Canada	36.0	30.9	33.1	0.76	0.85
Denmark	23.2	21.7	55.1	2.97	1.17
Western Germany[3]	35.2	22.5	42.3	2.14	1.08
Greece	35.4	25.5	39.3	3.55	1.35
Ireland	31.1	20.7	48.3	2.90	1.20
Italy	36.7	27.9	35.3	1.83	1.01
Japan	48.5	22.4	29.1	1.50	1.08
Luxembourg	59.2	24.4	16.4	0.49	0.87
Netherlands	34.5	23.6	41.9	2.06	0.98
New Zealand	42.5	36.8	20.8	0.59	0.78
Norway	29.4	38.8	18.3	0.02	0.45
Portugal	42.4	32.0	25.6	1.34	1.00
Spain	39.5	36.1	24.4	1.46	1.04
Sweden	39.7	31.6	30.7	0.17	0.63
Switzerland	14.7	36.8	48.5	0.12	0.66
Turkey	33.3	20.8	45.9	1.75	1.07
United Kingdom	30.1	24.5	45.4	2.69	1.16
United States	30.3	30.0	39.7	2.32	1.10

1. Emission estimates are detailed in the tables in Annex 1. They are based on IEA: *Energy Balances of OECD Countries* and on the emission factors calculated as in Tables II.1 and II.2. The figures presented in Table II.3 include emissions related to the end-use of electricity in each sector.

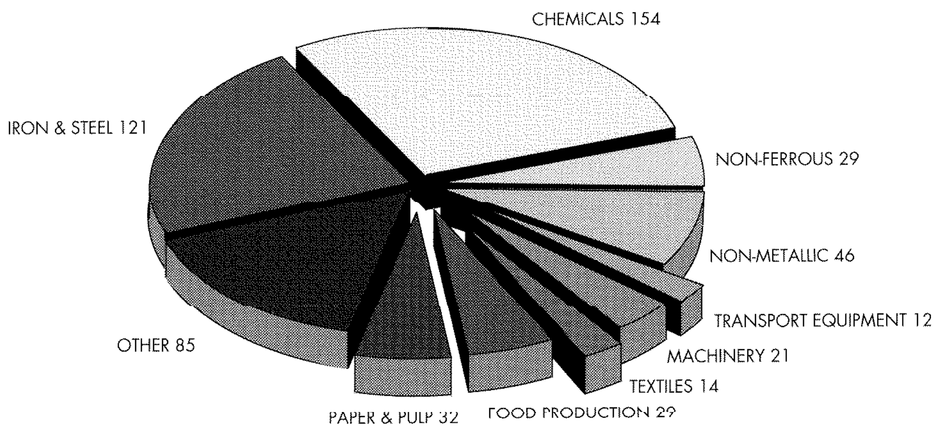
2. Expressed in Mt carbon/Mtoe.

3. Federal Republic of Germany before the unification of Germany.

Figure II.1

CO_2 Emissions from Industry, IEA[1] (1988)

(in Mt carbon)



1. Excluding the United States, where no comparable breakdown is available.

Figure II.2
CO_2 Emissions from Transportation, IEA (1988)
(in Mt carbon)

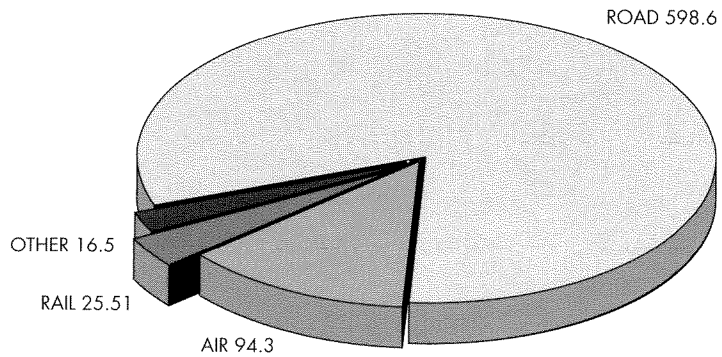
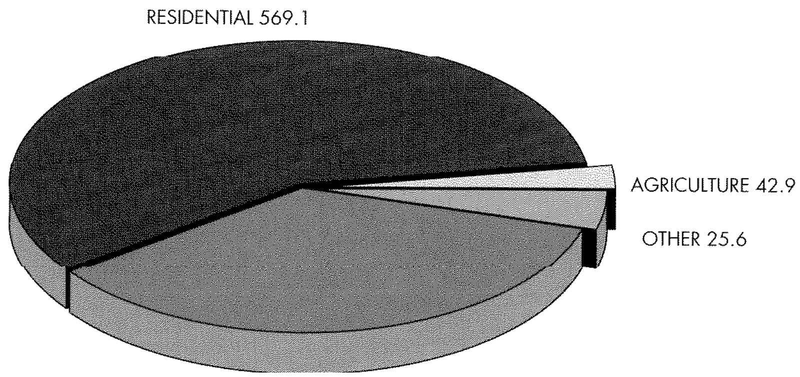


Figure II.3
CO_2 Emissions from Other Sectors, IEA (1988)
(in Mt carbon)



Further detail of the distribution of CO_2 emissions for subsectors or end-uses cannot be obtained using only IEA Energy Balance figures. As shown above, two subsectors are worthy of particular attention because of the large amount of CO_2 emissions they generate. In transport, the road transport subsector is responsible for 81.5% of the emissions produced by transport activities and 22% of total IEA CO_2 emissions. Among "other sectors", the buildings sector, composed of the residential, commercial and public subsectors (service sector), generates 93% of the emissions from this category and 34% of total IEA CO_2 emissions. A more detailed analysis of emissions in these two areas has therefore been attempted, using several energy data sources.

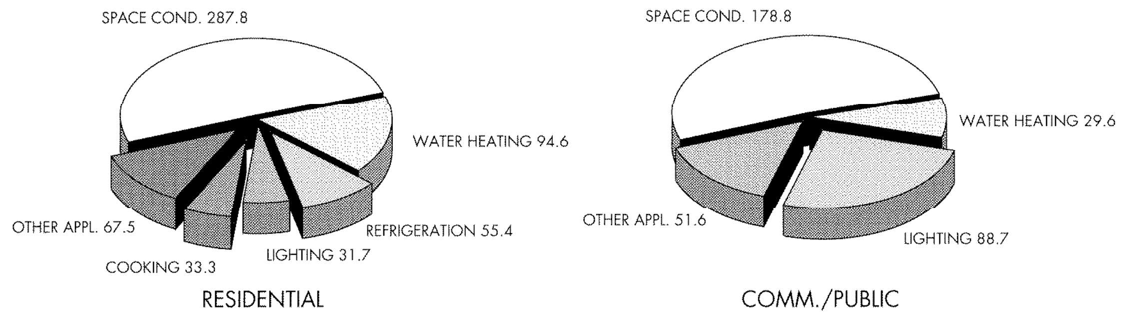
In the residential and commercial sectors, there are, for a number of IEA Member countries, country-specific estimates of energy consumption by various end-uses, such as heating, hot water, refrigeration and lighting. The energy requirements of the buildings sector of these countries account for about 93% of the total energy demand of the IEA service sector and 87% of that of the residential sector. These countries encompass a variety of climates and economic structures and can be regarded as representing the IEA as a whole. Their energy uses were therefore extrapolated to the remaining countries in order to obtain IEA-wide estimates of end-use demand, to which fuel-specific emission factors were then applied.

Although these estimates can only be considered indicative, they provide information that can be related to measures to reduce energy requirements and that depend crucially on the characteristics of these end-use sectors. Just over half of CO_2 emissions in the buildings sector of the IEA come from heating, cooling and ventilation, for which energy requirements are mainly influenced by improvements in the building shell or measures to reduce the heat load. The remaining emissions reflect energy requirements that depend on individual activities such as office automation and lighting, or on comfort and convenience features such as refrigerators or dishwashers.

Figure II.4

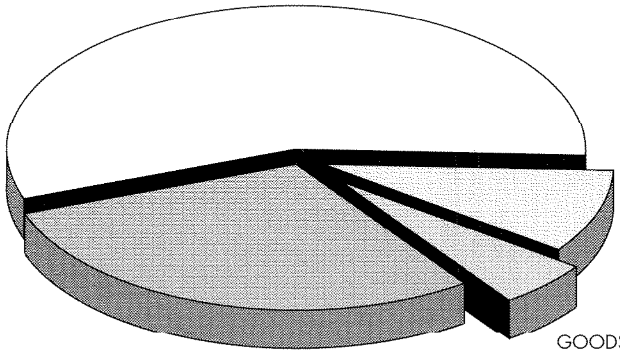
CO_2 Emissions from Residential and Service Sector, IEA (1988)

(in Mt carbon)



As far as the road transport subsector is concerned, calculations based on sources other than IEA: *Energy Balances of OECD Countries* can be used to produce estimates of CO_2 emissions from road transport for 1988 in IEA Europe (DRI, 1989), and country-specific data could be used to complete the geographical coverage of the data. Available data for IEA Europe provide breakdowns for passenger and freight transport by gasoline- and diesel-fuelled vehicles. Energy consumption data have been multiplied by the delivered fuel emission factor for oil to provide estimates for sources of CO_2 emissions by end-use in the road transport sector in IEA Europe, shown in Figure II.5.

Figure II.5
CO_2 Emissions from Road Transport, IEA Europe (1988)
(in Mt carbon)



In terms of CO_2 emissions, passenger transport and gasoline-fuelled vehicles are dominant. Because of the absence of electricity uses in the road transport sector, the relationship between carbon emissions and fuel consumption is linear and CO_2 emissions follow patterns of transport fuel use.

2. SELECTION OF MAJOR END-USE SECTORS AND SUBSECTORS

The objective of this section is to select certain major subsectors in each end-use sector so that the study covers a large share of emissions. The first criterion for the selection is important in terms of CO_2 emissions. The contribution of end-use sectors to the generation of traditional pollutants such as NO_x, SO_2 and CO is also taken into account.

2.1 Identification of largest contributors of CO_2 emissions and of national characteristics

Two main features of the energy sector of Member countries have a strong influence on the contribution of end-use to total CO_2 emissions. First, the size and structure of the industrial sector determines whether this sector or the building sector is the largest contributor. Energy-intensive industries, such as iron and steel, have a marked effect on the CO_2 emission levels of the industrial sector. Second, the share of non-fossil energy sources in the fuel mix for electricity generation is a decisive factor in setting priorities for CO_2 sectoral reductions. At least seven IEA Member countries use non-fossil energy sources (hydro- or nuclear power) for over 70% of electricity production. For these countries, transport fuels and heat used in industry and buildings are the major areas where significant CO_2 limitations would be beneficial. In other countries, particularly those that rely heavily on coal for electricity generation, the focus is shifted to electricity end-uses. In terms of energy efficiency efforts, this focus would be on specific electricity uses, such as electric motors in industry, or lighting and appliances in the building sector.

2.2 Contribution of end-use sectors to the generation of traditional pollutants

Estimates of sources of NO_x and CO emissions in 1986 for the OECD are presented in Figure II.6. For the OECD as a whole, transport is estimated to be responsible for 54% of energy-related NO_x emissions and stationary sources for the remaining 46%. The road transport sector is estimated to be responsible for 89% of total CO emissions from transport activities.

Estimates of the relative contribution of end-use sectors to total energy-related SO_2 emissions can be calculated for OECD Europe only for 1980. These estimates are presented in Figure II.7. For the OECD as a whole, coal combustion accounts for about 80% of energy-related SO_2 emissions and oil combustion for the remaining 20%.

These figures show that oil consumption in the road transport sector and fuel combustion in power plants are the two single largest contributors to emissions of traditional pollutants such as SO_2 and NO_x, which are involved in a variety of pollution problems, including acid deposition and urban ozone pollution, as well as climate change.

Figure II.6
NO_x and CO Emissions, OECD (1986)
(as a percentage of OECD total)

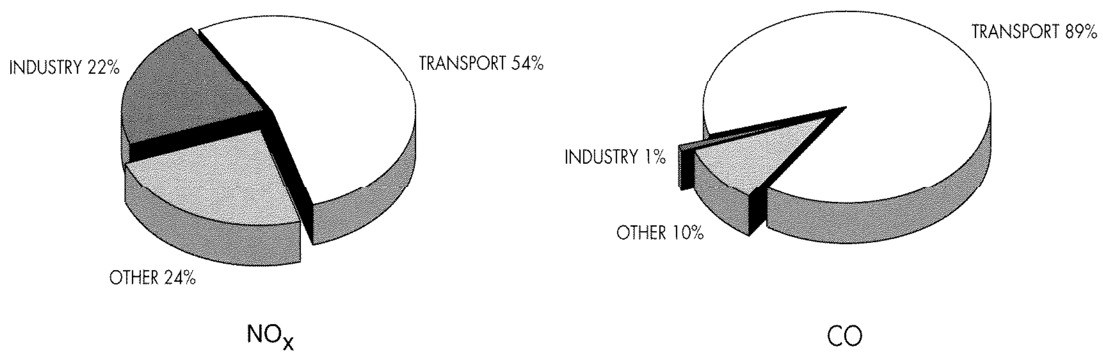
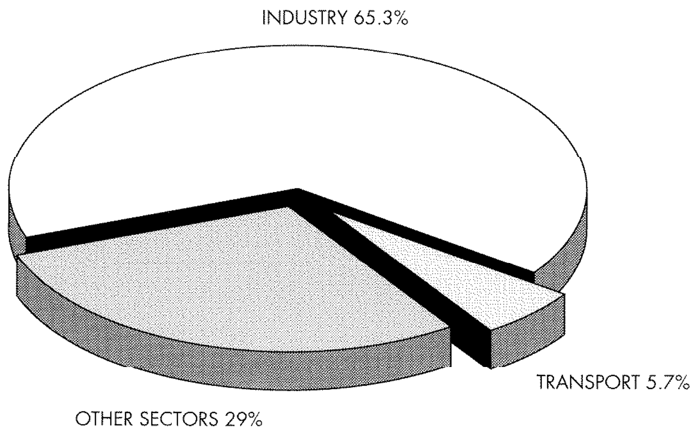


Figure II.7.
SO_2 Emissions, OECD Europe (1980)



2.3 Selection of key end-uses/subsectors

As the discussion above shows, several areas are worthy of particular attention within the framework of this study because they are large producers of CO_2 emissions in most IEA Member countries. These areas are road transport, energy use in the residential and service sectors (particularly electricity) and energy-intensive industries. These three categories together are responsible for over 75% of total CO_2 emissions in IEA Member countries. They are in addition major sources of other air pollutants, such as SO_2 and NO_x. Finally, as discussed in Chapter III, they have also displayed strong energy demand growth trends in recent years. These three areas will be the main focus of the analysis carried out in following chapters.

CHAPTER III

ENERGY DEMAND AND EFFICIENCY TRENDS

The first part of this chapter reviews historical developments in energy demand in the IEA in the major end-use sectors, while the second part concentrates on developments in energy efficiency. Because the parameters that influence energy demand vary among end-use sectors, the analysis developed in this chapter follows a sectoral approach, with an emphasis on the end-uses selected in Chapter II: industry (particularly energy-intensive industry), the residential, commercial and public sectors, and road transport (especially passenger cars).

1. EXAMINATION OF PAST TRENDS IN ENERGY DEMAND

1.1 Overview of sectoral trends

As a result of different energy demand growth rates, the sectoral distribution of energy demand in the IEA has changed significantly since the early 1970s. In 1973 industry absorbed 39.5% of TFC and the residential and service sectors together used 27.7%. By 1988, the share of industry had fallen 6.3 percentage points and that of the residential and service sectors had increased 1.8 percentage points. But these trends were overshadowed by the growth of the transport sector. In 1973, 25.8% of energy demand stemmed from this activity. Strong growth in transport energy demand over the next 15 years pushed the share of the transport sector to 30.5% in 1988. This sector surpassed the energy requirements of the service and residential sectors together and now ranks just behind industry.

These shifts in the structure of energy demand can to some extent be explained by structural changes in the economies of Member countries. Industry decreased its share of GDP from 37.6% to 33.8% between 1974 and 1988, while the contribution to GDP of the service sector increased from 57.8% in 1974 to 63.4% in 1988 (IEA, 1990a). The industrial sector is generally more energy-intensive than the service sector and reductions in industrial production at the expense of services foster overall reductions in energy requirements. These sectoral shifts in energy demand are also reflected in changes in the sectoral composition of CO_2 emissions. The industrial sector, which in 1980 accounted for more than 40% of CO_2 emissions, reduced its share to 34%, while the transport sector increased its contribution from 24% in 1980 to 28% in 1988. The other sectors, including residential and service, expanded their share from 35.4% to 38% during this period (see Table II.3 in Chapter II).

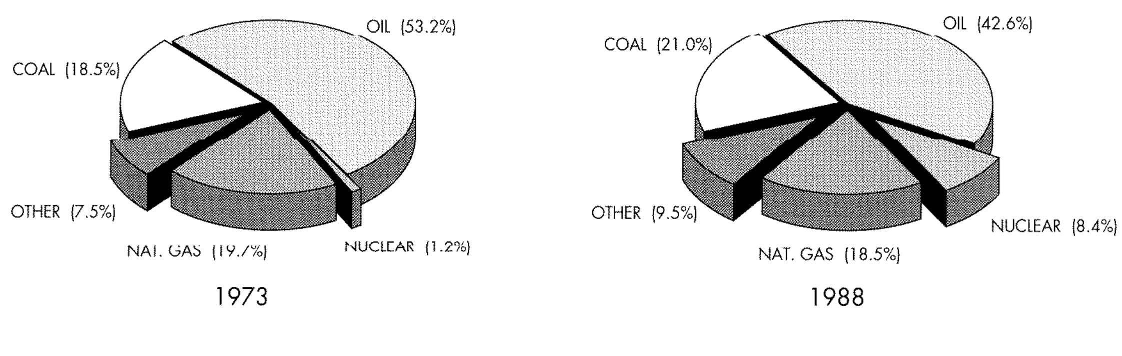
Table III.1
Trends in Sectoral Energy Demand in the IEA

	Energy Demand (Mtoe)			Annual Changes (%)		
	1973	1985	1988	1973-85	1985-88	1973-88
Industry	965.90	842.79	894.75	-1.13	2.01	-0.51
Residential	492.45	489.13	502.67	-0.06	0.91	0.14
Commercial/Public	209.92	250.78	273.63	1.49	2.95	1.78
Transport	635.35	735.33	823.30	1.22	3.84	1.74
Others	175.10	162.48	174.33	-0.62	2.37	-0.03
TFC	**2 478.72**	**2 480.51**	**2 668.68**	**0.01**	**2.47**	**0.49**
TPER	**3 312.82**	**3 509.51**	**3 762.84**	**0.48**	**2.35**	**0.85**

Source: IEA, 1990a.

The fuel pattern has also changed substantially over the last 15 years. Figure III.1 shows the structure of fuel use in IEA Member countries for 1973 and 1988. The most striking fact is the fall in the contribution of oil, from more than 52% in 1973 to 43% in 1988. Demand for natural gas remained relatively stable, while the contribution of nuclear energy increased from about 1% of TPER to 8%, and that of solid fuels from about 18% to 21%.

Figure III.1
Fuel Structure of Energy Requirements in the IEA (1973 and 1988)
(as % of TPER)

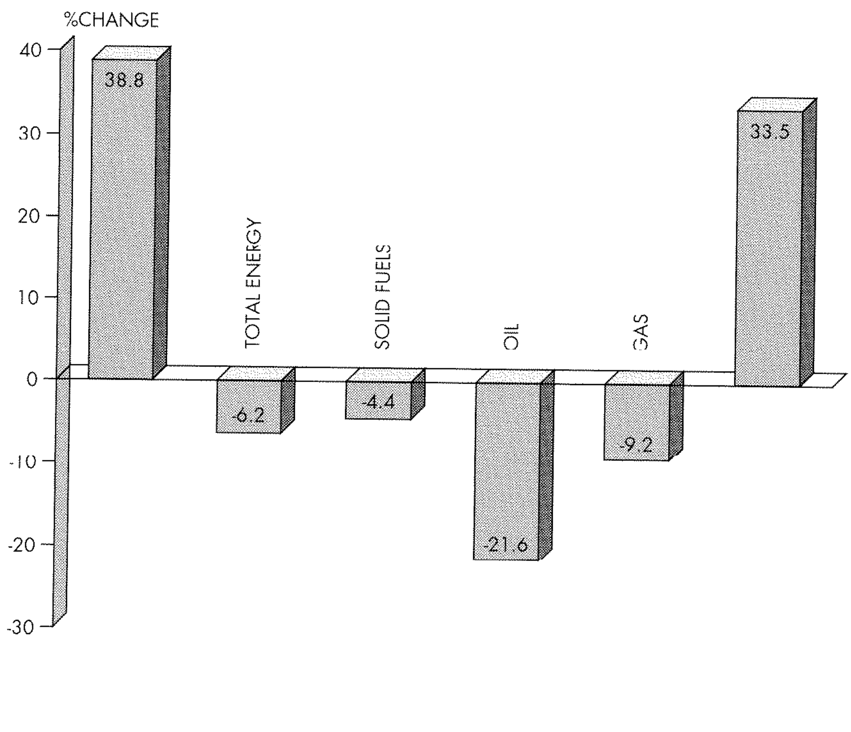


Source: IEA, 1990a.

1.2 Trends in energy demand in industry

The period from 1973 to 1988 saw OECD industrial production increase nearly 39% in real terms, while the amount of final energy used in the production of manufactured goods, in construction and in mining actually declined 6.2%. While there were decreases in the consumption of all fossil fuels, electricity use, in contrast, increased by nearly as much as the increase in industrial production, as shown in Figure III.2. In addition to efficiency improvements, structural change has tended to reduce the amount of final energy needed to produce goods. A recent study that examined changes in energy use and the economy in the United States from 1972 to 1985 (OTA, 1989) explains the slight increase in energy use over this period by two main factors. These are: forces that would add to energy use (growth in real output) and forces that act to reduce energy use (structural change, defined as changes in spending on final goods and services, non-engineering recipe changes in production and efficiency changes). The study finds that the structural changes are about half as important as the efficiency changes. A study by Jochem and Morovic (1988) indicates that about 20% of the change in energy use by the "EUR-10" countries is accounted for by intersectoral changes. This conclusion is also supported by a recent unpublished analysis carried out by the IEA for a number of countries' industrial sectors, which found that, in general, efficiency gains influenced energy intensity trends more than structural changes did from 1973 to 1985. So efficiency appears to be very important, but changes in the mix of goods and the contributions of the different branches to total output are also significant factors.

Figure III.2
Change in OECD Industrial Production and Energy Use (1973-1988)
(%)



(a) changes in the fuel mix

Both the changes in energy use over time and in relative energy use by industry branches reflect these structural and efficiency changes. The pattern of energy use by the industrial sector over time is shown in Figure III.3. After the oil crisis of the early 1970s, energy use declined at first, then increased, reaching a peak in 1979 at the time of the second oil crisis. After four years of decline, energy use began to increase, but in 1988 had not yet reached the level of 1973. The years of high oil consumption in industry coincided with those of high industrial energy use: 1973 and 1979.

The distribution of fuel use in industry in 1973 and 1988 for the IEA as a whole is shown in Figure III.4. In 1973, 53% of all energy consumption was in the form of oil, although industry's reliance on oil, at 38%, was less than that. Accordingly, industry used a higher percentage of coal and other solid fuels and natural gas. By 1988, oil consumption had declined from 53% to 43% for all energy use, with electricity making up the difference. For industry, oil consumption declined from 38% to 29% of energy use, although solids and natural gas use increased slightly. In industry, as with all final energy use, electricity made a substantial gain, from 14% in 1973 to 20% in 1988. These changes over time can be accounted for by the turnover of equipment using specific fuels, by changes in the endowment of specific fuels within IEA countries, or by more general application of multi-fuel-using equipment or preference for non-petroleum fuels. On the other hand, the increased share of electricity has also had a significant impact on industrial energy demand as far as primary fuel inputs are concerned. Reductions in final energy demand are partially compensated by increased primary energy inputs as a result of the replacement of other fuels by electricity, which is partially produced in thermal power plants with generally low conversion efficiencies. This is not only the case for industry but also for the residential and commercial sectors, where similar developments have taken place.

Figure III.3
IEA Industrial Energy Use
(Mtoe)

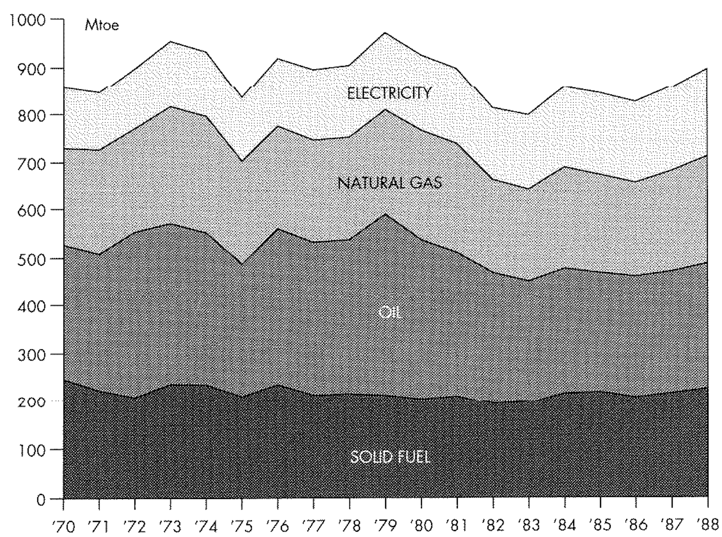
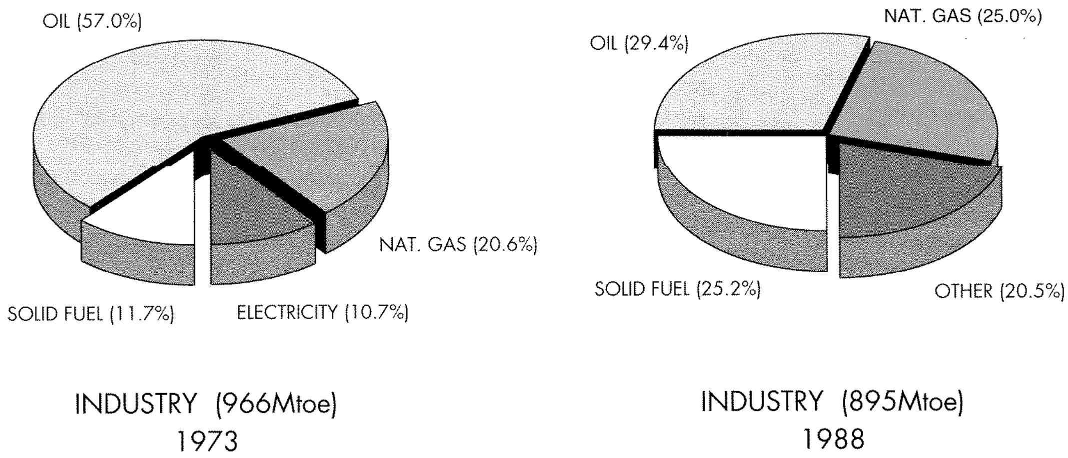
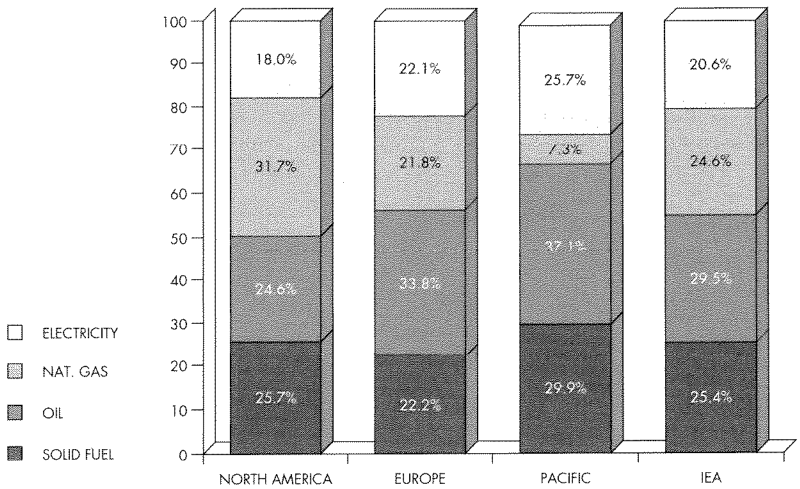


Figure III.4
Energy Use by Fuel in Industry in 1973 and 1988



There is considerable variation by region in the use of specific fuels, as shown in Figure III.5. North American industry consumed oil for only 25% of all industry energy use, while for both Europe and the Pacific, oil was the major industry fuel (34% and 37%, respectively). Natural gas use in North America was highest, at 32%, while it was lowest in the Pacific (7%), with the opposite being true for electricity — 18% in North America and 25% in the Pacific. Solid fuels cover 22 29% of industrial energy use. These variations reflect differences in the cost and availability of fuels, the natural resources of the countries involved and the distribution of industry branches within those countries.

Figure III.5
Industrial Fuel Shares by Region (1988)
(as % of TFC)



(b) changes in the energy demand of industrial branches

The distribution of branches of manufacturing (excluding mining and construction) for the IEA as a whole and for its three main regions in 1980 and 1988 is shown in Table III.2. North American energy use in 1980 accounted for approximately 53% of the IEA total. In North America, the major industry branches, in ranked order, were chemicals, iron and steel, and pulp and paper. No other single industry branch accounted for more than 5% of industry energy use. "Other" industry in North America accounted for nearly 30% of all industry energy use. The size of the "other" category in North America results from an inability to allocate energy use to industry branches based on producer information in the United States. For the IEA as a whole, chemical manufacturing was again the highest energy consumer among industry branches, followed by iron and steel, then pulp and paper. Non-metallic minerals account for 8% of total industrial energy use, and other metals, equipment and food accounted for about 5% each. The "other" category represents about 23% of energy use, in part because this category in North America is large.

IEA Europe accounted for 31% of total IEA energy consumption in manufacturing. Again, chemicals was the branch with the highest consumption, iron and steel was second, and non-metallic minerals was in third place. "Other" industry in Europe used 11% of manufacturing energy. The Pacific region used 16.5% of the IEA total for the manufacturing sector. In the Pacific region iron and steel accounted for the largest fraction of energy use, with the chemicals branch second and non-metallic minerals third, as in Europe. No other branch accounted for more than 5% of energy consumption except the "other" category, with 18%.

By 1988, the situation had changed only slightly. North American energy used in manufacturing had declined to slightly less than 50% of all IEA energy use. In North America chemicals accounted for 29% of energy use, an increase of four percentage points over 1980. Iron and steel and pulp and paper use was also a larger percentage. Food, equipment and non-ferrous metals each accounted for 7%, non-metallic minerals for 6% and "other" industry for 10%. Most of these changes are due to a better definition of the "other" category in 1988 than in 1980. Energy used for manufacturing in 1988 for the IEA as a whole had evolved in the same way as in North America.

Energy used for manufacturing in the Europe and Pacific regions did not change as much as for the IEA as a whole. Europe in 1980 used 32.2% of the total IEA energy consumed in manufacturing, while the Pacific region accounted for nearly 18%. Chemicals accounted for the largest share of energy use in Europe, with a slight increase from 30% to 34% between 1980 and 1988, offset by a slight decline in iron and steel, equipment and non-metallic minerals. The other industry branches required the same relative fraction of energy as before. The Pacific region changed little except for a reduction in the importance of iron and steel production from 33% to 28% of total energy use.

Table III.2
Evolution of Industrial Energy Use by Branch between 1980 and 1988

	1980				1988			
	IEA Total	N. America	Europe	Pacific	IEA Total	N. America	Europe	Pacific
Total[1] (Mtoe) of which :	866	455	269	143	813	406	262	146
Iron & Steel	19	14	21	33	20	17	19	28
Chemicals	26	25	30	24	30	29	34	25
Non-ferrous metals	5	5	4	5	6	7	4	5
Machinery & equipment	5	4	8	2	6	7	7	3
Non-metallic minerals	8	5	13	9	8	5	11	8
Paper	9	13	6	4	12	18	7	4
Food	5	4	7	5	6	7	7	4
Other	23	30	11	18	12	10	11	23

1. Total energy consumption differs from that indicated in Table III.1, as mining and construction are excluded here.

Sources: IEA, 1990a; Secretariat estimates for North America.

1.3 Trends in energy demand in the residential, commercial and public sectors

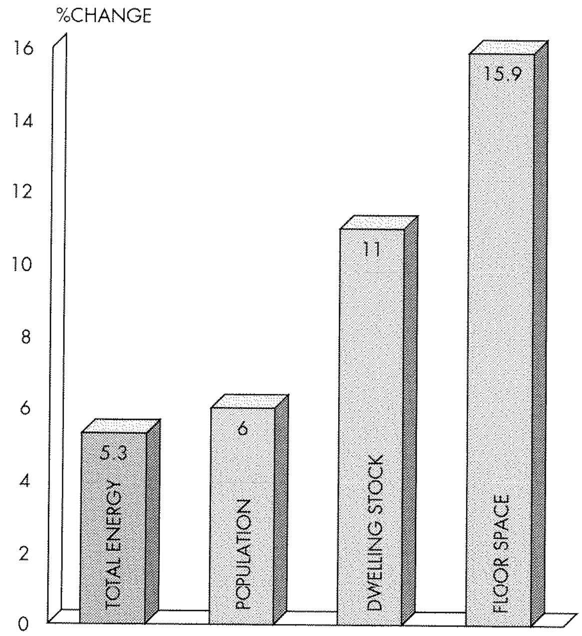
(a) residential sector

In the residential sector, a broad range of factors has influenced historical developments of energy demand. Changes in the housing stock, in the average floor space per person, in consumer preference or shifts towards fuels that provide a higher comfort level, such as electricity, all influence residential energy consumption. Between 1980 and 1988, IEA energy demand for the residential sector grew about 0.6% per year, the second lowest growth rate after that of industry. In the same period, the housing stock grew about 11% and floor space requirements increased 16%[1], while the population grew about 6%. This reflects the trend of developed economies towards smaller families and more square metres per person. A larger number of dwellings results in increased energy use for space heating. Smaller family size and an increased number of one person households mean more appliances are used. Energy demand per capita is therefore likely to rise. Figure III.6 illustrates the growth in residential energy demand, population, dwelling stock and floor space in the IEA between 1980 and 1988.

1. This figure is based on an extrapolation of data available for the six largest IEA countries. The United States, Canada, Japan, western Germany, Italy and the United Kingdom accounted in 1988 for more than 80% of the IEA's residential energy consumption.

Figure III.6

Relative Growth in Energy Requirements, in Population, in Dwelling Stock and in Floor Space in the Residential Sector in IEA Countries (1980-1988)



Developments in the residential sector were also marked by significant shifts in demand patterns over this period, as shown in Table III.3. The share of solid fuels and oil products decreased from more than 41% in 1980 to about 33% in 1988 while natural gas's share rose 3.3 percentage points and that of electricity rose 4.4 points, mainly because of fuel substitution, energy efficiency improvements and greater ownership of new appliances, which boosted electricity demand.

Table III.3

Energy Requirements in the Residential Sector of the IEA

(shares and Mtoe)

	1980 (Mtoe)	(%)	1988 (Mtoe)	(%)	Annual Changes 1980-1988 (%)
Solid Fuels	53.8	11.4	55.0	10.9	0.3
Oil Products	141,4	29,9	112,8	22,4	-2,9
Natural Gas	164.9	34.9	192.0	38.2	1.9
Electricity	112.0	23.7	141.4	28.1	3.0
Heat	0.4	0.0	1.5	0.3	16.8
Total	472.6	100.0	502.7	100.0	0.8

Source: IEA, 1990a.

Tables III.4 and III.5 show the breakdown of residential energy use by category of end-use in 1988 in the IEA as a whole, in absolute values and in percentage shares. Such end-use data exist for countries that account for about 93% of the residential energy use of the IEA[1]. Total IEA figures presented in these tables are the result of extrapolating these data to all IEA residential energy consumption. These tables reveal that space conditioning and heating end-uses constitute by far the largest single element in the energy consumption of the residential sector.

Table III.4

Energy End-Use by Category in the Residential Sector of the IEA (1988)[1]

(Mtoe)

	Space Conditioning and Heating	Water Heating	Refrigeration	Lighting	Cooking Appliances	Other	Total
Coal	44.8	7.3	0.0	0.0	2.8	0.0	55.0
Oil	94.1	17.0	0.0	0.0	1.7	0.0	112.8
Gas	129.4	46.7	0.0	0.0	16.0	-0.0	192.0
Electricity	34.1	19.6	28.3	16.1	8.9	34.4	141.4
Heat	1.5	0.0	0.0	0.0	0.0	0.0	1.5
Total	303.8	90.6	28.3	16.1	29.4	34.5	502.7

1. Derived from a selected number of countries for which end-use data are available.

Table III.5

Energy End-Use by Category in the Residential Sector of the IEA (1988)[1]

(percentage shares)

	Space Conditioning and Heating	Water Heating	Refrigeration	Lighting	Cooking Appliances	Other	Total
Coal	81.5	13.3	0.0	0.0	5.1	0.0	100.0
Oil	83.4	15.1	0.0	0.0	1.5	0.0	100.0
Gas	67.4	24.3	0.0	0.0	8.3	-0.0	100.0
Electricity	24.1	13.9	20.0	11.4	6.3	24.3	100.0
Heat	100.0	0.0	0.0	0.0	0.0	0.0	100.0
Total	60.4	18.0	5.6	3.2	5.8	6.9	100.0

1. Derived from a selected number of countries for which end-use data are available.

1. Canada, western Germany, Ireland, Italy, Japan, the Netherlands, Norway, the United Kingdom and the United States.

(b) commercial and public sector

Data for the commercial and public sector are less readily available than for other sectors. Activities in this sector comprise very diverse services, ranging from educational, financial and real estate to public services, including street lighting. So far, energy demand analyses have not particularly focused on this multifaceted sector. Compared to industry, the commercial and public sector is less energy-intensive; compared to the residential sector there are fewer market barriers; and compared to the transport sector, technology is much more dispersed, which means that more sophisticated approaches and data collection are needed for energy demand analysis.

Nevertheless, in recent years, some research activities have been directed at this sector, largely because of the substantial growth of electricity demand for services. Table III.6 shows that between 1980 and 1988, the final energy demand of the service sector increased 1.5%, though different fuel types exhibited very different developments. While demand for oil products and natural gas decreased slightly and solid fuel consumption remained fairly stable, the consumption of electricity rose by 4.6% annually. In other words, electricity in the service sector of the IEA increased its share from about 24% in 1980 to 42% in 1988.

Table III.6

Energy Requirements in the Commercial and Public Sector of the IEA

(shares and Mtoe)

	1980 (Mtoe)	(%)	1988 (Mtoe)	(%)	Annual Changes 1980-1988 (%)
Solid Fuels	4.3	1.8	4.4	1.6	0.3
Oil Products	74.9	30,9	70.6	25.8	-0.7
Natural Gas	83.5	34.4	81.8	29.9	-0.3
Electricity	79.9	23.9	114.5	41.8	4.6
Heat	0.2	0.0	2.3	0.8	38.7
Total	242.7	100.0	273.6	100.0	1.5

Source: IEA, 1990a.

Figure III.7 illustrates the growth in total energy and electricity demand as well as the increase in economic output of the service sector[1]. The economic output of the commercial/public sector in the OECD during the last decade has exceeded the growth of both the industrial sector and GDP. It grew between 1980 and 1988 by 34.7%, while GDP increased by 26.2% and industrial activity by only 21.6%. The service sector generated about 63% of the OECD's total GDP in 1988.

These developments can be partially explained by structural changes in the service sector. Activities that require more office space and that consequently increase electricity needs for

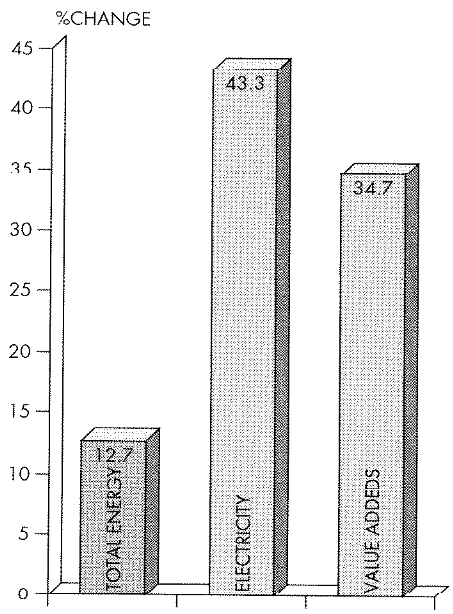
1. Economic output in the service sector is defined as value added.

lighting, office automation and space conditioning/ventilation have grown at the expense of traditional activities. In the United States, for example, between 1985 and 1987 the subsectors finance/real estate/business services and transport/communication experienced the strongest growth rates. The activities of these sectors increased annually by 4.4% and 5.1%, respectively, whereas total sectoral activity grew 4.2% per year. Another reason for these developments is the market penetration of new technology. As for the residential sector, the ownership level of electrical equipment increased during the last decade. Some studies indicate that the spread of office equipment, such as personal computers, copiers and telefax machines, as well the growth of space conditioning systems for heating, cooling and ventilation in some countries, significantly influenced electricity demand.

Figure III.7

Relative Growth of Energy and Electricity Demand, and Value Added in the Commercial and Public Sector of IEA Countries (1980-1988)

(%)



Tables III.7 and III.8 show the breakdown of commercial energy use by category of end-use in 1988 in the IEA as a whole, in absolute values and in percentage shares. As in the case of the end-use data presented for the residential sector, such data exist for nine countries, which account for about 87% of the commercial energy use of the IEA[1]. Total IEA figures presented in these tables are the result of extrapolating these data to all IEA commercial energy consumption.

1. Canada, western Germany, Ireland, Italy, Japan, the Netherlands, Norway, the United Kingdom and the United States.

Table III.7
Energy End-Use by Category in the Commercial Sector of the IEA (1988)[1]
(Mtoc)

	Space Conditioning and Heating	Water Heating	Lighting	Other Appliances	Total
Coal	3.2	0.2	0.0	1.0	4.4
Oil	49.6	14.5	0.0	6.2	70.3
Gas	65.5	7.5	0.0	8.8	81.8
Electricity	43.2	5.7	45.6	19.8	114.3
Heat	2.0	0.3	0.0	0.0	2.3
Total	163.4	28.3	45.6	35.9	273.2

1. Derived from a selected number of countries for which end-use data are available.

Table III.8
Energy End-Use by Category in the Commercial Sector of the IEA (1988)[1]
(percentage shares)

	Space Conditioning and Heating	Water Heating	Lighting	Other Appliances	Total
Coal	72.4	4.2	0.0	23.4	100.0
Oil	70.6	20.6	0.0	8.8	100.0
Gas	80.0	9.2	0.0	10.8	100.0
Electricity	37.8	5.0	39.9	17.4	100.0
Heat	85.9	14.1	0.0	0.0	100.0
Total	59.8	10.3	16.7	13.1	100.0

1. Derived from a selected number of countries for which end-use data are available.

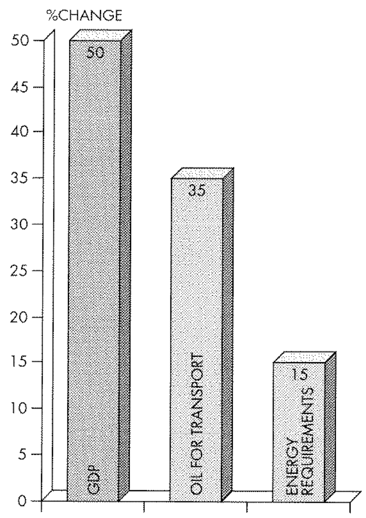
1.4 Trends in energy demand in the road transport sector

(a) evolution of oil demand

Road transport accounts for over 80% of the energy used by the transport sector as a whole, and 99% of the energy used in road vehicles comes from oil. Oil use for road transport in the IEA has grown 34% since 1974. Figure III.8 shows that though this is less than GDP growth, the evolution of oil use in road transport is of particular importance because it has been growing faster than both total energy requirements and consumption in other end-use sectors, especially since 1985. In addition, the rate of increase itself is growing: 1.9% in 1986, 3.7% in 1987 and 4.5% in 1988. As a result, energy use for road transport is absorbing a growing share of IEA oil and total IEA energy.

Figure III.8

Growth of GDP, Energy Requirements and Road Transport Energy Use in IEA Countries between 1974 and 1988

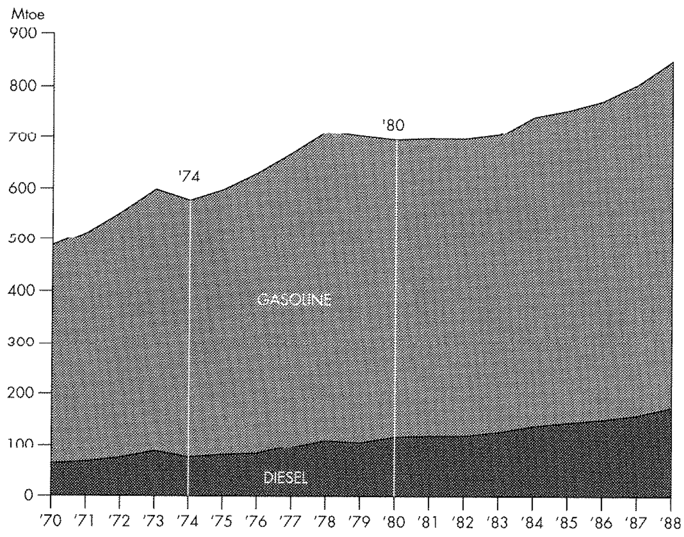


Source: IEA, 1990a.

Though increases in the price of oil following the two oil shocks did have an effect on the energy use of the road transport sector, this demand reduction was short-lived, as can be seen in Figure III.9. In addition, since 1973, there has been little substitution in the road

Figure III.9

Oil Demand for Road Transport in the IEA (1970-1988)



Source: IEA, 1990a.

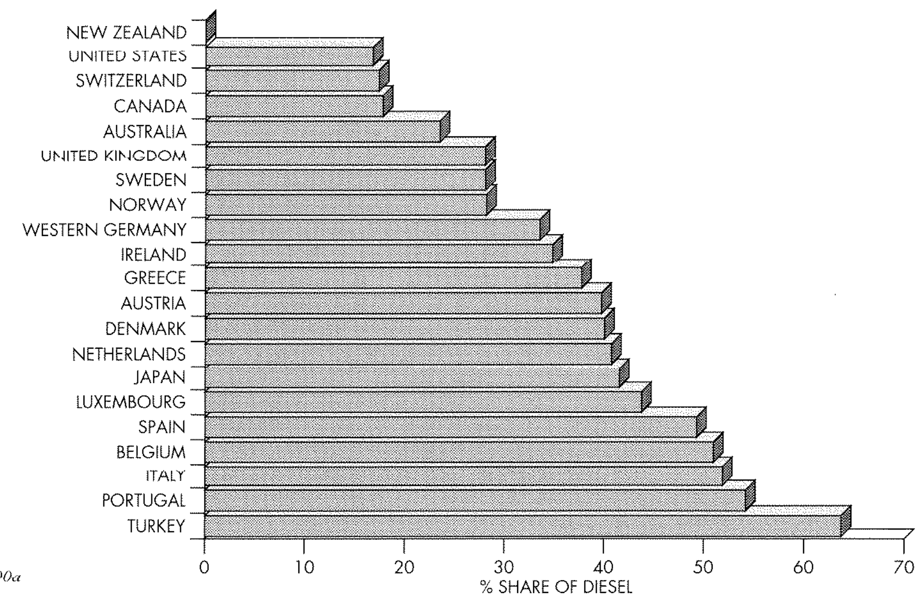
transport sector, unlike the major shifts away from oil that took place in electricity generation and other end-use sectors. About 1% of road vehicles currently use fuels other than gasoline or diesel fuel, such as CNG, LPG and ethanol. Only Canada, Italy and New Zealand have undertaken substitution programmes involving any significant fraction of their vehicle fleet, and even in these countries, fuels other than oil still contribute less than 5% to the energy needs of the transport sector.

(b) share of gasoline and diesel fuels

The only change in the fuel mix of the road transport sector has been an increase in the use of diesel fuels, from 14.5% of oil consumption for road transport in 1974 to close to 26% in 1988. This is an IEA average; actual shares of diesel in road transport in 1988 varied considerably among countries, as Figure III.10 shows.

While figures on gasoline and diesel deliveries are readily available, the actual use of these fuels in the different road transport subsectors, such as passenger and goods transport, is not definitely known. Estimates available for eight countries are presented in Table III.9. Passenger motor vehicle transport is estimated to account for over half of the oil consumption of the transport sector and represents about one out of every three barrels of oil consumed in the OECD. In the United States, private cars use about 60% of the oil consumed in road transport, the remainder being absorbed by buses and goods transport. In Belgium, western Germany and the Netherlands, private road transport uses about 65% of oil consumption, public passenger road transport only 5% and goods road transport about 30% (Tardieu, 1989). In Japan, passenger cars account for 51% of road transport oil consumption, buses about 4% and goods vehicles 45% (Energy Conservation Centre, 1989).

Figure III.10
Share of Diesel in Road Transport in IEA Member Countries (1988)



Source: IEA, 1990a

Table III.9

Gasoline and Diesel Use for Passenger and Goods Road Transport in Selected IEA Countries

(in Mtoe)

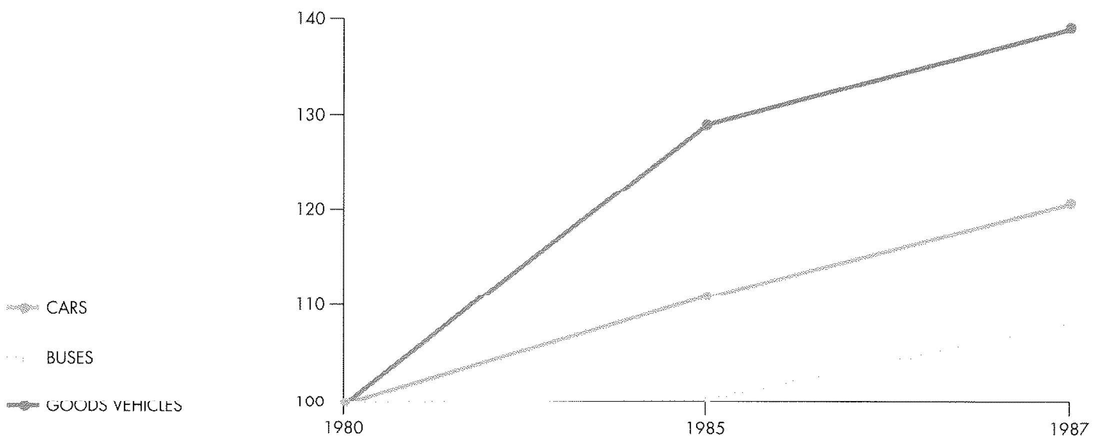
	1980 Gasoline	1980 Diesel	1980 Total	1988 Gasoline	1988 Diesel	1988 Total
Canada						
Passenger cars	17.82	0.12	17.94	16.52	0.17	16.69
Other vehicles	10.20	4.53	14.73	8.82	6.72	15.54
Total	28.02	4.65	32.67	25.34	6.89	32.23
Western Germany						
Passenger cars	24.30	2.10	26.40	26.80	5.10	31.90
Other vehicles	-	8.50	8.50	2.20	9.70	11.90
Total	24.30	10.60	34.90	29.00	14.80	43.80
Ireland						
Passenger cars[1]	-	-	-	0.66	0.05	0.71
Other vehicles	-	-	-	0.24	0.46	0.70
Total	1.09	0.38	1.47	0.90	0.51	1.41
Japan						
Passenger cars	21.85	2.54	24.39	28.11	4.23	32.34
Other vehicles	5.44	12.63	18.07	3.00	20.80	23.80
Total	27.29	15.17	42.46	31.11	25.03	56.14
Norway						
Passenger cars	0.99	0.01	1.00	1.28	0.03	1.31
Other vehicles	0.39	0.72	1.11	0.49	1.06	1.55
Total	1.38	0.73	2.11	1.77	1.09	2.86
Sweden[3]						
Passenger cars	3.18	0.16	3.34	3.63	0.18	3.81
Other vehicles[4]	0.27	1.14	1.41	0.40	1.33	1.73
Total	3.45	1.30	4.75	4.03	1.51	5.54
United Kingdom						
Passenger cars	18.10	0.22	18.32	22.50	0.74	23.24
Other vehicles	2.40	6.06	8.50	2.45	9.31	11.76
Total	20.54	6.28	26.82	24.95	10.05	35.00
United States						
Passenger cars[2]	-	-	-	287.00	6.00	293.00
Other vehicles	-	-	-	40.00	60.00	100.00
Total	300.00	52.00	352.00	327.00	66.00	393.00

1. Reported as private vehicles.
2. Reported as light-duty vehicles.
3. Figures in 1988 columns are for 1987.
4. Gasoline-fuelled vehicles are trucks, buses and motorcycles; diesel-fuelled vehicles are trucks and buses.

Sources: Country submissions; IEA, 1990a; Bundesminister für Verkehr, 1989 (Germany).

Fuel data distinguishing between different vehicle types or usage categories are not available as time series covering all IEA Member countries. More precise clues to the relative growth rates of different subsectors and their possible contribution to increases in fuel use can be gained by examining the evolution of traffic indicators, summarised in Figure III.11 for 1980 to 1987. These figures reflect the strong increase in mobility and road transport in the IEA, with marked differences among subsectors. In terms of vehicle-kilometres, the goods road transport sector has grown most rapidly since 1980 in IEA countries, with an increase of about 40%, followed by cars with vehicle-kilometre growth of a little over 20%. Traffic related to public road transport (essentially buses) increased only 8% during the same period.

Figure III.11
Road Traffic Volume in IEA Member Countries (1980-1987)
(in vehicle-kilometres)



Excluding bus traffic in Australia, Canada, Greece, Ireland, New Zealand and Portugal, as no appropriate data are available.
Sources: ECMT, 1989, and IRF, 1989.

2. ENERGY EFFICIENCY DEVELOPMENTS

2.1 Overview of energy efficiency developments

(a) definition of energy efficiency indicators

The progress of energy efficiency within the demand trends examined in the previous section needs to be evaluated with care because it is intertwined with so many other factors affecting demand. An energy efficiency improvement is defined as any action by a producer or consumer of energy that reduces the use of energy without affecting the level of service provided. Therefore, the first step to narrow down the search for energy efficiency developments is to eliminate the effect of changes in levels of service. The most obvious changes of this type are related to fluctuations in economic output or sectoral activity.

This is why energy intensity, calculated by a variety of performance ratios dividing energy use by a unit of economic output, is considered a basic indicator of energy efficiency. Used appropriately, energy intensities are an effective way to compare the energy performance of different economic activities over time, within a given country or internationally.

When considering the energy use and economic output of a country, energy intensity is usually defined as the ratio of TPER to GDP. One problem with this definition is that trends in overall energy intensity reflect changes in the amount of energy needed to produce a unit of GDP and that these changes can be due not only to efficiency improvements, but also to structural changes within the economy, to changes in goods traded with other countries and to changes in the fuel mix. The calculation of sectoral energy intensities, such as oil or electricity intensities, for a range of consuming sectors can clarify some of these differences, though they tend to relate TFC to economic output, thereby eliminating the impact of conversion losses, for instance in electricity generation. This effect is likely to be substantial given the marked increase in electricity generation and use in IEA countries over the last 15 years.

Another problem in the calculation of both overall energy intensities and sectoral intensities is the choice of the denominator reflecting economic output. If international comparisons of energy intensities are to be made, as in the analysis presented here, a common denominator has to be found. If this denominator is expressed in monetary units as is the case for GDP or value added, this poses the problem of conversion into a single currency. In OECD analyses, the US dollar is usually used for international comparisons and national currencies are converted using the 1985 exchange rate. The GDP values obtained in this manner are biased by currency rate fluctuations in the base year and should be treated with caution. Disaggregated analyses of sectors and subsectors can avoid the use of monetary units altogether by using physical units, such as tons of steel produced, floor space heated or distance travelled. Nevertheless, the use of physical units as a denominator can mask differences in the processes and energy-using equipment used and in the nature and quality of the end-products.

International comparisons of the evolution of energy intensity should also take into account the fact that different economies may start from a different basis, according to their current level of efficiency and economic development. Countries that already have relatively low levels of energy intensity because they have already achieved large improvements in energy efficiency, or less developed countries, which tend to use less energy to produce goods, may not display as strong rates of energy intensity decline as countries where the potential for energy efficiency is still large. In addition, country-specific factors, such as climate, distances between cities, size of homes as well as social and cultural characteristics, influence the level of energy intensity and limit the scope of international comparisons.

(b) evolution of energy intensity

In the 1960s and early 1970s energy demand expanded at about the same rate as GDP growth and energy intensity remained fairly stable. Overall energy intensity started to decline significantly after the first oil price hike in 1973. Table III.10 depicts the trends in

TPER/GDP ratios in IEA regions between 1973 and 1988. During this period, overall energy intensity in the IEA declined by about 1.8% annually. In recent years, however, the decline has slowed substantially. Among other factors, the decrease of energy prices in real terms between 1982 and 1988 certainly contributed to weakening the decline in energy intensity.

Although these energy intensities are a result of the combined effects of efficiency improvements, structural changes and fuel substitution, energy efficiency has had a major impact on intensity. For example, in the United States, two thirds of the decrease in energy use between 1972 and 1985 came from efficiency improvements and the remaining third from changes in the composition of economic output, with shifts away from basic industries to less energy-intensive industries and services (OTA, 1990).

Table III.10

TPER/GDP Ratios for all IEA Countries[1]

						Average Annual Growth Rates (%)
	1973	1980	1986	1987	1988	1973-1988
North America	0.60	0.55	0.46	0.46	0.45	-1.9
Pacific	0.41	0.35	0.30	0.29	0.29	-2.2
Europe	0.52	0.46	0.43	0.43	0.42	-1.5
IEA Total	0.55	0.49	0.42	0.42	0.41	-1.8

1. Measured in toe per $1 000 of GDP at 1985 prices and exchange rates: intensities reflect the combined effects of efficiency improvements, structural changes and fuel substitution.

Source: IEA, 1990a.

The TPER/GDP ratio provides only an aggregate picture of energy demand trends. Reflecting changes in the pattern of energy supply in the IEA, various fuels have experienced substantial differences in intensity developments over the last 15 years. Such disparities are particularly pronounced for oil consumption and electricity demand. While the amount of oil necessary to produce one unit of GDP has decreased almost 40% since 1973, electricity intensity increased between 1973 and 1988 because of the market penetration of electrical appliances in the residential sector and of air conditioning and ventilation systems in the service sector. Structural changes in industrial production, as well as shifts towards more electricity-intensive processes, for example in the steel and machinery industries, have also played a part in increasing electricity intensity.

2.2 Energy efficiency developments in industry

(a) energy efficiency indicators for the industrial sector

Trends in final energy use, industrial production and energy intensity in the IEA as a whole since the early 1970s are summarised in Figure III.12, with values in 1973 taken to equal 100. Industrial energy intensity is the ratio of energy use in industry to industrial production[1]. Except during recessions in 1973/75 and in 1982, industrial production climbed steadily from 100 in 1973 to 139 in 1988. Energy use declined almost immediately after oil price increases, but also in 1985 even though energy prices had actually been declining for several years. The index for final energy intensity in industry declined from 100 in 1973 to 68 in 1988. The decline appears steady except for a slight increase in 1979 and a flattening since 1986. In light of the very dramatic energy price changes over the entire period, what is confounding is that the trend in the reduction of final energy intensity is both gradual and steady. Although there are periods when energy use declined with sharp increases in prices, there is no discernable indication that energy intensity responded in step with energy prices.

This steady decline in energy intensity can be explained by a number of factors, many of which affect the rate of improvement in industrial productivity. Economic forces, such as the rate of growth of industrial branches and changes in relative prices of production factor inputs — energy, other materials, capital and labour — are one set of factors. There are also technological factors, such as the rate of stock turnover, and access to technology, that influence the rate at which energy intensity may change. Changes in the fuel mix, such as the increased share of electricity, also have an impact on industrial energy intensity. Taking into account the conversion efficiencies, however, these changes can also result in increased demand for primary energy.

Economic considerations are of primary importance in understanding changes that occur within the industrial sector. Industrial growth in an economy is not distributed equally among industrial branches. If energy-intensive industrial branches grow at a faster rate than the industrial sector as a whole, and this growth is not offset by declines in energy intensity, then industrial energy intensity will increase. With the exception of the chemicals branch, energy-intensive industries have declined relative to the rest of industry and this accounts for some of the decline in energy intensity over time. Relative prices, of energy and other factor inputs, are also important because they influence the recipe that is chosen for the production of goods. If energy costs increase relative to those of other production factors, then it is likely that an enterprise will try to reduce energy costs by substituting less expensive fuels or by reducing energy use.

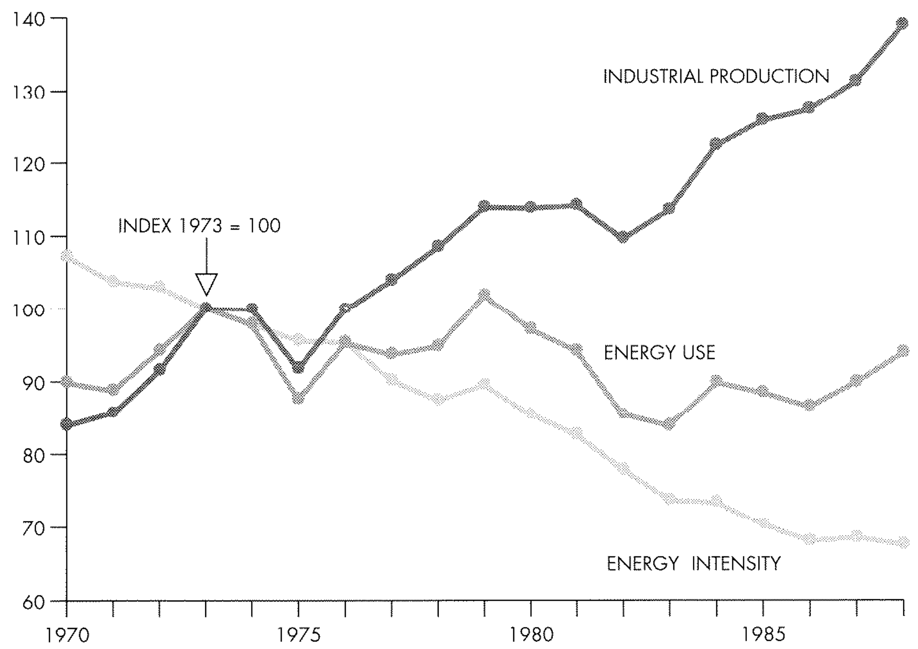
Technical factors are also important, though they are not independent of economic factors such as the relative prices of production factors and the rate of growth and of stock turnover. Some industrial equipment, like vehicles and packaging equipment, may last for ten years or less; other equipment, such as blast furnaces and kilns, may last for 40 or more years. As this equipment comes to the end of its useful life, it is usually replaced with newer, and

1. Indicators of industrial production in real prices are taken from the quarterly publication of the OECD : *Indicators of Industrial Activity*, Paris. The indicators measure total manufacturing output in real terms.

generally more efficient, equipment. But the decision to replace this equipment will be influenced by the health of the industry and its prospects. If an industry is in decline, equipment will be scrapped rather than replaced. If the expectation is for sluggish growth, the decision to invest in new equipment may be postponed until the prospects for the use of that equipment are brighter. Access to, and knowledge about, more efficient equipment is also an important technical factor and is likely to be better in industries and countries with a high rate of investment in research and development.

Figure III.12

Energy Performance of Industry, IEA (1970-1988)



Despite the many diverse factors that affect industrial energy use in various countries, it is possible to examine how efficiencies have changed in some cases by examining the evolution of energy use indicators based on energy consumption per metric ton of product (though such figures should be treated with caution because, as mentioned above, differences may be related to different processes and products). Although a uniform set of data does not exist to allow the examination of all of industry in all IEA countries, it is possible to look at selected industries (iron and steel, pulp and paper, and cement). Evidence from these three industries suggests that energy efficiency has improved dramatically since the early 1970s in all regions of the IEA. There is scattered evidence from several studies that suggest this has occurred as well outside these three industries. A recent publication in the United States (EIA, 1990) compares energy intensity ratios between 1980 and 1985 for 16 of the 20 Standard Industrial Classification "two-digit" manufacturing branches and for manufacturing as a whole. For all of manufacturing, energy intensity declined over this five-year period by 25.1%, with a range from 11% for primary metals to 43.6% for non-electrical machinery. Within those industry branches that are most energy intensive, pulp and paper energy intensity declined 13%, chemicals 17.6% and non-metallic minerals 23%. Food processing intensity declined 22.9% and textile mill products 16.3%. In western Germany (Schaefer, 1988), the energy used for industrial process heat declined from 53.5 Mtoe in 1973 to 39.4 Mtoe in 1982, while industrial production increased 3.3%. Consequently, the energy intensity of process heat use declined 28.3%.

(b) energy efficiency in steel production

The production of steel includes a number of steps. Iron ore is first reduced to pig iron in a blast furnace using coke as the primary fuel, or is directly reduced to sponge iron. The ore is usually processed before being reduced in a blast furnace, either by being shaped into pellets (usually at the ore removal site) or by a process called sintering. The pig iron from the blast furnace is further purified into steel in a basic oxygen furnace (BOF), an electric arc furnace (EAF) or using the now mostly antiquated open-hearth method. Nearly two-thirds of the developed world's supply of steel is produced using the BOF process. The crude steel is either moulded into ingots or is directly cast into shapes such as beams or bars. The steel is then finished by rolling, annealing, pickling, coating, or other treatments.

A wide variety of factors influences the energy intensity of the steelmaking process, and many of these factors depend on the endowment of resources within a particular country. The coke required for the production of pig iron may be produced by the steel industry or imported. The iron content and preprocessing of ore have a bearing on the amount of energy required to reduce the ore to pig iron. The method used to refine the pig iron into steel will also determine the energy content of the steel: The open-hearth process requires much more energy than does either the EAF or the BOF, but can process more scrap iron than the BOF. The EAF can be charged with nearly all scrap, thus saving on the pig iron input to the process. If charged with cold scrap, however, the EAF requires far more energy to convert the charge to steel than does a BOF fired with molten pig iron. If the steel is first cast into ingots, the ingots must be reheated before being broken down into billets, sheets, etc. In continuous casting of steel, this reheating step is eliminated, thus reducing the energy content of steel products. If a country is a net exporter of steel ingots, it avoids the energy used in rolling and finishing the steel, leaving that, as well as the significant value added and contribution to GNP, for the importing country.

Table III.11 shows, from 1980 to 1988, changes in energy per metric ton of crude steel output, the per cent of EAF used for steelmaking and the per cent of continuous casting used. The change in energy use, calculated based on IEA energy use data and OECD steel production data, suggests that North America improved its energy use by 41% from 1980 to 1988. Europe and the Pacific also improved, but not quite so dramatically, with the average for all IEA countries being an improvement of about 22%. It requires approximately 8.5 gigajoules (GJ) to produce a metric ton of crude steel (tcs) using the EAF technology, because the bulk of the charge is scrap, not pig iron. A BOF, in comparison, requires approximately 19 GJ/tcs. Thus shifting from open-hearth steelmaking to EAF steelmaking, as North America did over this period, will substantially alter the energy efficiency of the process. In 1980, North America used continuous casting (CC) for only about 21% of steel production. By 1988 this percentage had increased to 62.5%. There were similar improvements in each of the regions: Europe increased CC from about 38% in 1980 to almost 90% in 1988 and the Pacific from about 56% to about 92%.

Table III.11

Changes in IEA Steel Production (1980-1988)

	North America	Europe	Pacific	IEA Total
% change in energy use/metric ton crude steel	41.0	14.6	3.7	21.9
% EAF 1980	27.3	28.5	23.2	26.3
% EAF 1988	32.0	31.6	28.7	31.4
% CC 1980	21.1	38.5	56.2	38.7
% CC 1988	62.5	89.8	91.9	77.5

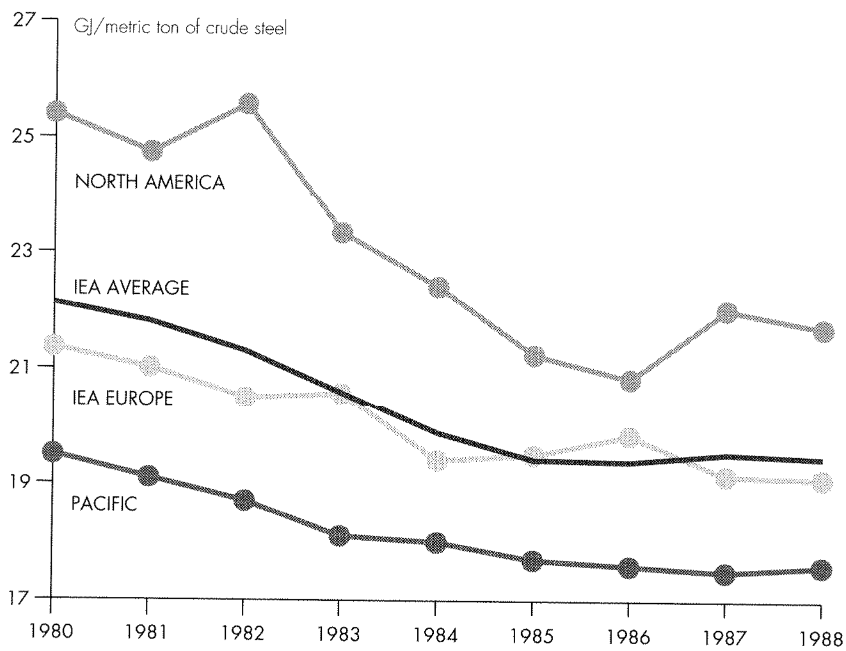
Changes in the energy efficiency of steel production for the three major regions of the IEA and for the total IEA area is shown in Figure III.13, on the basis of data in steel production in 15 IEA countries that account for more than 91% of IEA steelmaking and are representative of the IEA regions. Steelmaking is examined by production process, differentiating between ore processing, ironmaking, crude steel production, rolling and finishing, and other activities associated with the steelmaking process. Cokemaking is intentionally excluded from the analysis, which focuses only on the steelmaking and finishing processes. In 1980 a metric ton of crude steel required 25.4 GJ to produce in North America, compared with only 19.5 in the Pacific. In 1988, these figures had been reduced by 14.6% and 8.2%, respectively. European experience falls between these two extremes, as does the IEA total, with an improvement over the period of 11.8%. Within this period, 1982 and 1986 stand out as years when intensity of steel production increased, especially in North America. These years were also those when production of steel was at a minimum.

Although there may be many reasons for these regional differences in energy efficiency, it is instructive to examine their effect on energy consumption. In 1988, Europe produced 38.7% of the steel produced in the IEA, North America 29.7%. In North America that steel was produced using 21.7 GJ per metric ton, in Europe using 19.1 GJ. If the nearly 250 million metric tons of steel in these regions had been produced at the same energy intensity level as in the Pacific (17.6 GJ/tcs), the savings would have amounted in 1988 to 15.6 Mtoe — a figure corresponding to about 1.7% of all IEA industry energy use. Moreover, this lowering of energy consumption will reduce carbon emissions by 18.6 Mt, a decline in North America and Europe of 14% of the carbon emitted in the iron and steel industry.

(c) energy efficiency in the pulp and paper industry

Paper products are produced through a sequence of processes that begin with the preparation of wood and its conversion into pulp. There are three major ways this

Figure III.13
Energy Intensity in Steel Production by IEA Regions



conversion can occur: through a mechanical process of reducing the wood to fibre; through a chemical process; or through a combination of the two. When the pulp has been formed and made it may be bleached, then formed into a mat of board, paper or pulp and dried. The two most energy-intensive stages of this process are the pulping and drying, but many other factors also affect the energy requirements of pulp and paper production.

Pulping is one of the most energy-intensive steps in papermaking. Mechanical pulping consumes more electric energy while chemical processes consume more thermal energy. In North America in 1986, chemical processes accounted for about 75% of all pulp produced, mechanical pulping for about 20% and combination methods for the remaining 5%. In the IEA as a whole, chemical processes accounted for 72%, mechanical methods 23% and combination methods 5%. Mechanical methods may yield up to 95% of the dry volume of wood as pulp; chemical methods yield about 50%. In chemical methods, the lignins removed from the wood are burned to raise the steam needed for both pulping and drying of paper and pulp, with the chemicals being recovered through pyroprocessing. If mechanical methods are used, the thermal energy required for drying must be produced by fossil fuels. In North America, one of the fastest growing methods of pulping is the thermo-mechanical method, used to produce lower grades of paper such as newsprint. Through recycling of the steam used in making chemical and thermo-mechanical pulp, improved efficiencies in the pulping process have been realised in all regions of the IEA.

The other major energy-consuming process is formating and drying pulp and paper. The washed and (about half the time) bleached pulp is formed into a sheet, the water is pressed out of the sheet, then the sheet is dried, typically by steam-heated rollers. About half of the energy used in producing market pulp or paper is used in formation and drying. One energy saving step widely adopted since the early 1970s is the use of hoods over the drying line to retain the heat near the paper.

Two other important considerations in the energy intensity of the pulp and paper industry are the amount of waste paper used and the trade in market pulp. Recycled waste paper requires less energy to re-form into paper than does virgin wood[1]. Even more than the use of waste paper, importing dried pulp tends to reduce the energy used to produce paper since it does not have to be de-inked. The Pacific region is the leader in recycling paper, while North America accounts for about 95% of all pulp and paper exports.

Table III.12
Pulp and Paper Industry in the IEA (1980-1986)

	North America	Europe	Pacific	IEA Total
GJ/t pulp 1980	18.4	18.8	18.3	18.5
GJ/t pulp 1986	17.0	15.9	9.4	16.2
GJ/t pulp 1980	21.0	17.2	11.6	20.0
GJ/t pulp 1986	19.1	14.7	8.8	17.3
% waste paper 1980	14.4	35.3	4.9	18.5
% waste paper 1986	18.1	35.2	48.2	26.7
% pulp imports 1980	0.2	62.3	34.5	-
% pulp imports 1986	2.0	59.6	38.4	-

As shown in Table III.12 in 1980 all regions of the IEA produced a metric ton of pulp by using about 18 GJ, when calculated as if all the energy were directed just at pulp production. A more accurate measure is energy intensity per metric ton of paper, which reflects the fact that waste pulp can substitute for virgin wood pulp and the extent to which imports supplement domestically produced pulp and wastes. For example, the Pacific region in 1980 used 18.3 GJ to produce a metric ton of pulp but only 11.6 GJ to produce a metric ton of paper. This smaller energy requirement for paper reflects the fact that nearly 5% of the pulp was derived from wastes and this region accounted for 37.5% of all pulp imports (about 15% of Pacific production of pulp). North America, in contrast, used 21 GJ for each metric ton of paper produced, while producing pulp with similar efficiency as the Pacific region (18.4 GJ). This was true even though North America used over 14% of wastes for pulp while the Pacific in 1980 used only about 5%. This difference is explained by the fact that North America accounted for 95.8% of IEA pulp exports in 1980. North America accounted for about the same fraction of exports in 1986.

1. Waste paper requires 4-5 KJ/metric ton to convert into pulp, most of it electricity, compared with 4.8 GJ for mechanical pulping and 1.5-5.7 GJ for chemical pulping, not including the processing of wood feedstocks (Garrett-Price, *et al.*, 1987).

Energy intensity in pulp and paper production in 1986 decreased in all IEA regions, but most dramatically in the Pacific region. Paper production's energy use declined 24% in six years from 11.6 GJ in 1980 to 8.8 GJ in 1986. Most of this improvement occurred through increased recycling, from 4.9% to 48.3%, and process improvements. Over the same period, European energy intensity in pulp and paper declined nearly 18% and North American intensity 9%. On average, intensity declined by 15% for the IEA as a whole, which amounted to a reduction in energy use of about 9.3 Mtoe from 1980 to 1986. This represents 1.1% of total IEA industry energy consumption in 1986, from an industry that used about 6% in 1980.

(d) energy efficiency in the cement industry

Most of the technological changes that have occurred in the cement industry world-wide are related to energy use. Energy accounts for about half of the total costs of producing cement. Most of the differences in energy efficiency in cement production have resulted from changes in the method of producing clinker, the product that comes from the kiln and is ground into cement. As a by-product of the chemical reaction in the kiln, about 0.136 metric tons of carbon are released for each metric ton of clinker produced.

The two basic ways to produce clinker are the wet process and the dry process, with variations (semi-wet and semi-dry). The wet process permits more homogenisation of kiln feed and reduces the need to grind raw materials but requires large quantities of heat for pyroprocessing, since the water must be evaporated prior to the chemical reaction that forms cement. The energy required for evaporation is about 2.09 GJ per metric ton of clinker in the wet process, which in 1980 required a total of about 5.86 GJ per metric ton of clinker produced. The dry process, using a long rotary kiln, required about 4.04 GJ per metric ton. With the introduction of pre-heaters to the kiln feed, which uses exhaust heat, the energy requirements of the dry process drop to about 3.35 GJ per metric ton. The further addition of pre-calciners reduces the energy requirements to about 3.14 GJ.

These additions to the pyroprocessing of cement were introduced in the 1950s but did not make significant gains in some countries until the early 1970s. One reason is the long life of a kiln (usually put at 40 years, though some kilns in the United States have been in operation for 75 years). It was estimated in the United States in 1983 that only 29.7% of clinker production was from kilns installed after 1972, with 23.6% coming from kilns installed before

Table III.13

Cement Industry, Selected Countries and Europe

(energy use per capita in toe)

	Europe	United States	United Kingdom	Japan
Kiln, GJ/t 1980	4.2	5.1	5.3	n.a.
Energy, GJ/t 1980	4.7	6.0	5.7	n.a.
Energy, GJ/t 1988	4.4	4.4	5.1	n.a.
% change in intensity (1980-1988)	6.0	28.4	10.2	14.0

1960. The average efficiency of these earlier kilns is about 6.28 GJ per metric ton, compared with about 4.5 GJ for the later kilns.

Table III.13 provides information on cement production for the United States, the United Kingdom, Japan and Europe (average of ten countries). It shows that all four improved their energy use for cement production between 1980 and 1988.

2.3 Energy efficiency developments in the residential sector

(a) energy efficiency indicators for the residential sector

Energy intensity indicators for the residential sector typically relate energy demand to population, dwellings or floor space. Though it is possible to calculate energy use per capita or per dwelling, the floor space of the housing stock is not usually available, particularly as time series. Table III.14 shows that, between 1980 and 1988 for the IEA as a whole, the energy per capita ratio remained virtually unchanged, though it decreased in North America (-0.7% per year) and increased in Europe (0.7% per year) and in the Pacific region (2.2% per year). Electricity intensity increased in all regions between 1980 and 1988. In the IEA as a whole, per capita electricity requirements grew more than 2% annually.

Table III.15 shows that for most of the countries selected in different regions of the IEA, energy requirements per square metre decreased between 1980 and 1987. In the United States, western Germany, Italy and Sweden, average energy demand per unit of area declined by about 13%. In the United Kingdom and Japan, specific energy demand remained little changed; Japanese energy demand per square metre is about 50% lower than that of the other countries shown. By contrast, electricity intensity increased in all seven countries, which together represent over three-quarters of total IEA electricity demand.

Table III.14

Residential Energy Intensity Indicators

(energy use per capita in toe)

	Total Energy			Electricity		
	1980	1988	*Annual Changes (%)*	1980	1988	*Annual Changes (%)*
North America	1.06	1.00	-0.69	0.27	0.32	1.93
Pacific	0.25	0.29	2.16	0.10	0.13	3.15
OECD Europe	0.50	0.52	0.70	0.09	0.11	2.53
IEA	0.65	0.66	0.04	0.16	0.18	2.21

Source: IEA, 1990 a.

The reduction in overall intensity is basically a result of improvements in the efficiency of space conditioning, brought about by increased insulation, improved burners and distribution systems, and better energy management. These improvements were largely induced by increases in energy prices, and supported by government policies to increase efficiency, such as more stringent building codes. As a result, energy requirements for space heating, which account for approximately 62% of IEA residential energy demand, substantially decreased in the late 1970s and early 1980s. Table III.16 illustrates these trends in countries where data are available (expressed in megajoules per square metre per year: $MJ/m^2/yr$).

Table III.15

Residential Energy Intensity Indicators

(toe per '000 square metres, without climatic corrections)

	Total Energy			Electricity		
	1980	1987	*Per cent Change 1980-1987*	1980	1987	*Per cent Change 1980-1987*
United States	21.69	18.69	-13.9	5.64	5.82	3.1
Canada	27.57	21.54	-21.9	7.57	8.51	12.3
Japan	9.06	9.02	-0.5	3.50	3.83	9.4
Western Germany	26.55	22.96	-13.5	3.91	4.00	2.5
Italy	20.55	17.86	-13.1	2.29	2.40	5.0
Sweden	24.54	21.31	-13.2	5.96	7.97	33.7
United Kingdom	21.58	21.90	1.5	4.44	4.44	0.1

Sources: IEA, 1990; Schipper, 1988; Swedish Government.

Table III.16

Space Heating Intensities

($MJ/m^2/yr$)

	1970	1980	*Changes 1970-1980 (%)*
Denmark	1 186	718	-39.5
Western Germany	918	855	-6.9
Italy	749	535	-28.6
Sweden	922	642	-30.4
United Kingdom	672	642	- 4.5

Source: Giovannini and Pain, 1990.

(b) factors influencing energy efficiency

In the IEA, about 60% of residential energy consumption goes to space conditioning, about 18% to water heating, about 6% to refrigeration and cooking, and more than 3% to lighting. These various end-use categories have very different characteristics, which influence potential energy efficiency improvements. Energy requirements for space conditioning are mainly influenced by improvements in the building shell or other measures to reduce the heat (or cooling) load, such as the passive use of solar energy, as well as by efficiency improvements in space heating technology, including boilers or building management systems. The technical level of appliance energy efficiency is largely a matter of technological developments. The difference in turnover of the capital stock between space conditioning and domestic appliances is one to five, with appliances replaced every ten to 15 years. Initiatives that aim to increase energy efficiency, such as retrofit programmes or boiler replacement, need to take these differences into account.

Over the last two decades, most IEA Member countries have introduced thermal regulations for new buildings. Some countries, such as Sweden and Germany, have also introduced thermal requirements for old buildings in the case of major construction work. Some countries, such as Germany and Austria, encouraged retrofitting with soft loans or tax deductions. As for appliances, high energy prices have historically provided strong inducement to increase energy efficiency, and manufacturers increased their products' efficiency in order to be more competitive when consumers were sensitive to energy costs in the decade following the first big increase in energy prices. The price impact was often accompanied by government action. In seeking to reduce energy demand and increase efficiency, several governments promoted energy efficient technology and induced the manufacturing industry to enhance the energy efficiency of their products. Governments initiated voluntary agreements to increase efficiency between appliance manufacturers and authorities, as in western Germany and Japan, or enacted mandatory appliance standards, as in the United States, where energy prices are relatively low.

With the weakening of energy prices, however, energy consumption became a minor factor in determining consumer choice, and technological progress slowed. Nevertheless, since the late 1970s, electric utilities in some Member countries, particularly in North America, have become increasingly involved in demand-side activities. This has particularly been the case for lighting and refrigeration, but also for weatherisation programmes, which reduce the heating and cooling load.

Developments in energy demand in the residential sector are the result of a number of factors, including the impact of energy policies and changes in disposable income and consumer behaviour. As noted earlier, dwelling numbers and floor space have increased throughout the IEA countries and the number of household appliances has increased. Both factors significantly affect energy demand developments. Heat demand per unit of floor space has decreased, but this has been partly offset by the increase in housing stock.

The consequences of these developments have been more pronounced for electricity demand, as electricity is the energy source for most residential appliances and not widely used for space heating. Most types of residential appliance used today began to penetrate the market in the early 1960s and continued to do so in the 1970s and 1980s. Consumers enjoy their convenience and demand is growing steadily. Accelerated market penetration of existing and new domestic appliances has been the driving force for electricity demand developments in OECD countries. One example is dishwashers, for which significant increases can be observed between 1973 and 1986. In 1973 in western Germany, only 7% of households were equipped with dishwashers, whereas in 1986 almost every third household owned one. The saturation level has not yet been reached, so additional energy demand can be expected as dishwashers and other equipment with similar market characteristics further penetrate the market. Virtually all residential appliances have exhibited similar developments and it is likely that new technology will contribute to additional electricity requirements. One example is high-definition television (HDTV), for which electronic concerns see a major future market in the residential sector. Current HDTV sets have a significantly higher electricity demand per unit than conventional sets. As demand for this technology increases, however, companies operating in a competitive market will want to improve the performance of their equipment. As a result, in future years efficiency improvements can be expected that are comparable to those that standard television sets have displayed over the last three decades. Similar developments have occurred for certain office equipment, such as personal computers.

Increases in ownership levels often offset the impact of efficiency improvements on energy demand. For instance, per-unit energy consumption by dishwashers in western Germany fell more than 60% between 1973 and 1986, but higher use more than compensated; electricity demand for dishwashers nearly doubled. Nevertheless, market penetration will eventually reach saturation levels and technological progress will continue — for example, recently developed microchips used for battery-driven laptop computers significantly reduce the electricity consumption of PCs — though consumer demand for new equipment must be considered in projections of electricity demand.

2.4 Energy efficiency developments in the commercial and public sector

(a) energy efficiency indicators for the commercial and public sector

There are two different types of energy intensity indicators for the service sector. The first is similar to the one used in the industrial sector as it relates energy use to economic output. The second, derived from the ratio of energy use to floor space, is similar to the energy intensity indicator used for the residential sector. As far as data permit, both types are calculated here. But because national accounts do not fully take account of the economic output of public services, the value-added figures given for the service sector may not reflect total sector energy requirements; public offices, for example, are not included in the measurement of economic output. The ratio of energy use to value added is a sufficiently accurate indicator for the energy performance of the service sector, particularly for monitoring trends over time, though cross-country comparisons may be biased and should be treated with caution.

Tables III.17 and III.18 show the energy and electricity needed to produce one unit of economic output for selected countries for which comparable data exist, for OECD Europe and for the OECD as a whole in 1980 and 1987. As in the case of the developments in the

Table III.17

Trends in Energy Intensity of Service Sector

(Mtoe per value added in 1985 US$)

	1980	1987	*Annual Changes (%)*
Belgium	67.06	55.07	-2.78
Denmark	34.12	30.99	-1.36
Western Germany	62.49	65.35	0.64
Japan	30.56	28.88	-0.81
Netherlands	14.28	17.74	3.14
Norway	59.14	50.78	-2.15
Spain	26.33	31.23	2.47
Sweden	71.64	58.94	-2.75
United States	64.83	52.50	-2.97
OECD Europe	57.74	48.51	-2.46
OECD	59.61	49.41	-2.65

Sources: IEA, 1990a; OECD, 1990; Swedish Government.

Table III.18

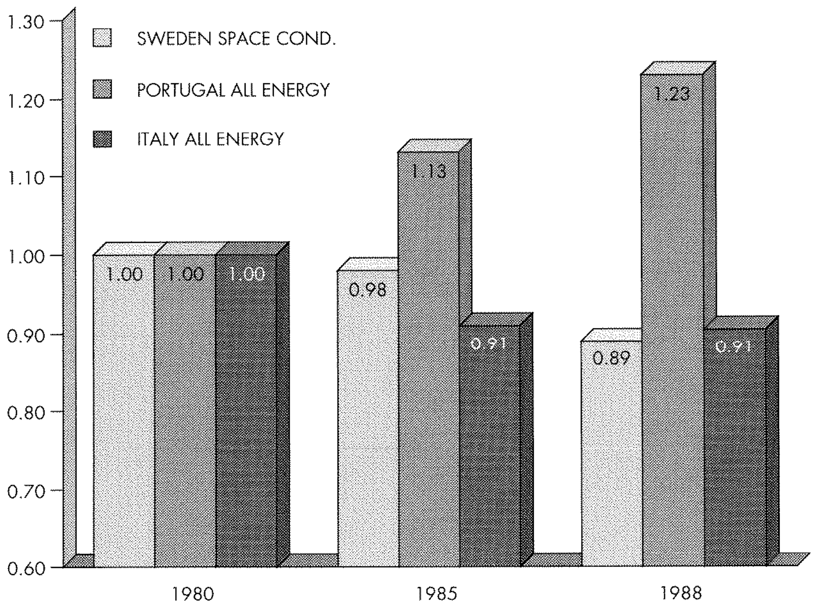
Trends in Electricity Intensity of Service Sector

(electricity use in Mtoe per value added in 1985 US$)

	1980	1987	*Annual Changes (%)*
Belgium	9.67	10.44	1.10
Denmark	15.10	15.26	0.15
Western Germany	15.46	16.98	1.35
Japan	7.63	9.70	3.50
Netherlands	14.28	15.42	1.10
Norway	34.05	36.76	1.10
Spain	12.62	16.37	3.78
United States	21.86	22.29	0.28
OECD Europe	14.95	16.76	1.65
OECD	18.32	19.49	0.89

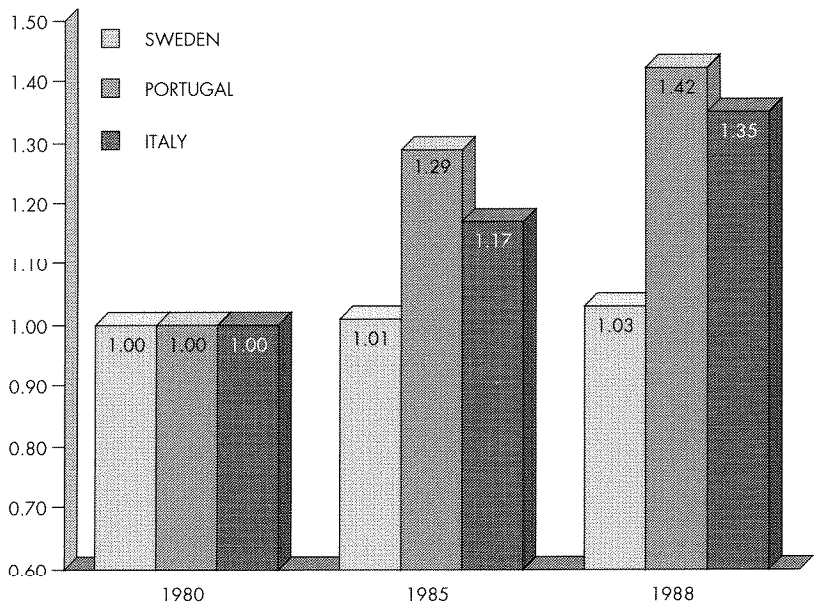
Sources: IEA, 1990a; OECD, 1990.

Figure III.14
Commercial Sector Energy Indicators
(energy use/square metre, 1980 = 1)



Source: Country submissions.

Figure III.15
Commercial Sector Energy Indicators
(electricity/square metre, 1980 = 1)



Source: Country submissions.

residential sector, energy intensity in the commercial and public sector declined between 1980 and 1987 while energy productivity increased 2.7% per year on average. In contrast, the electricity intensity of the service sector grew less than 1% per year between 1980 and 1987. These trends reflect improvements in the thermal efficiency of building shells of commercial premises and the trend towards more electricity-intensive services. They are also due to the market penetration of new electric equipment involved in office automation. In the IEA as a whole, approximately 60% of final energy demand goes to space conditioning, about 17% to lighting, 10% to water heating and 13% to other uses, such as process heat and mechanical work. Lighting covers a substantially larger share than in the residential sector.

The second type of energy intensity indicator is the one that relates energy use to floor space. It is well suited to assessing the level of thermal or lighting efficiency, though it is not an appropriate measure of the energy productivity of the sector, as it does not capture economic factors. Furthermore, data on floor space exist only for a limited number of IEA countries. Figures III.14 and III.15 show changes in energy and electricity intensity per floor area between 1980 and 1988 in Italy, Portugal and Sweden. For Sweden and Italy, specific energy requirements declined, whereas for Portugal they increased about 22%. Electricity intensity rose in all three countries, especially Portugal and Italy, with increases of over 30%.

(b) variations in energy intensity

There are important variations in energy intensity between various services and Member countries. Only a few studies have analysed energy use per square metre. Table III.16 shows an evaluation of these studies, undertaken by Giovannini and Pain (1990). Energy intensities are provided for three different activities — hotels/restaurants, hospitals and retailing — in Japan, Norway, Switzerland and the United States. Although the years for

Table III.19

Energy Intensities of the Service Sector

($MJ/m^2/year$)

	Year	Activity	Electricity	Fuel	Total	Share of electricity (%)
Japan	1976	hospitals	84	336	420	20.0
Norway	1977	hot./rest.	252	210	462	54.5
Switzerland	1985	hospitals	240	800	1 040	23.1
Switzerland	1985	retail	600	850	1 450	41.4
United States	1979	retail	431	554	985	43.8

Source : Giovannini and Pain 1990

which the quantification was carried out vary, there are obviously substantial differences in both energy use and fuel structure. For example, Swiss retail services used 1 450 MJ/m^2 in 1985, whereas in the United States in 1979 only 985 MJ/m^2 were required. The share of electricity in Norwegian hotels/restaurants was 54% in 1977, while in Japan, where the type of cooking requires the fast heat provided by natural gas, the same activity consumed only 25% of its energy as electricity. Such regional and structural differences are highly relevant to an assessment of the scope for further achievements in energy efficiency. Climatic conditions vary among countries, the structure of the service sector is different, the appliance or housing stocks may have different vintages and culturally related preferences may dominate. Though this is not an exhaustive list of factors explaining the differences shown in Table III.19, all these variables have to be carefully evaluated to avoid generalisations and misleading conclusions.

To carry out an assessment of further saving potential, it is also necessary to analyse time series. But it is difficult to follow trends in intensity over time because the necessary structural surveys are usually not undertaken regularly. A study for Switzerland indicates that square metre energy requirements for public administration offices decreased between 1975 and 1985 from 720 to 710 MJ/m^2/year, and that in the insurance business energy intensity increased from 850 to 1 050, essentially because of increased electricity consumption.

2.5 Energy efficiency developments in the road transport sector

(a) energy efficiency indicators for the road transport sector

Oil consumption in the road transport sector is a function of the number of vehicles in use, the distances travelled and the energy consumption of each vehicle. The basic energy efficiency indicator used for road transport relates consumption to distance travelled (expressed in litre/100 km or miles per gallon). The energy consumption of each vehicle depends on the type of vehicle considered, its weight and engine capacity, and a variety of other technical characteristics. A number of other factors, such as driving behaviour, maintenance, and road and traffic conditions, can also influence actual fuel consumption, though it is difficult to assess their relative effect with precision. These elements need to be considered alongside energy efficiency indicators in order to provide a full picture of energy efficiency developments in the road transport sector in recent years.

(b) evolution of fleet size and mileage

The first determinant of the evolution of fuel consumption in the road transport sector is the size and growth of the vehicle fleet. Data presented in Table III.20 show that the stock of goods vehicles and of passenger cars has more than doubled in the IEA as a whole since 1970. Growth has been strongest in Japan and in Europe, where stocks of passenger cars multiplied by 3.4 and 2, respectively, between 1970 and 1987. The strongest growth in car population in the Pacific region occurred between 1970 and 1979, whereas in IEA Europe it

Table III.20
Road Vehicle Stocks in the IEA (1970-1987)

	Passenger cars				Goods Vehicles			
	1970	1980	1987	% increase 1970-1987	1970	1980	1987	% increase 1970-1987
North America								
fleet 1 000s	95 846	131 856	149 417	56	20 237	36 569	44 471	120
cars/1 000 inhab.	423	524	554	31				
Australia-New Zealand								
fleet 1 000s	4 703	7 108	8 802	87	1 121	1 710	2 324	107
cars/1 000 inhab.	301	398	450	49				
Japan								
fleet 1 000s	8 779	23 660	29 478	236	8 282	13 178	20 194	144
cars/1 000 inhab.	85	203	241	183				
Sweden								
fleet 1 000s	2 288	2 883	3 367	47	145	182	246	70
cars/1 000 inhab.	286	345	400	40				
IEA Europe								
fleet 1 000s	50 154	84 864	103 502	106	5 876	8 328	10 136	72
cars/1 000 inhab.	171	271	319	86				
IEA Total								
fleet 1 000s	159 482	247 488	291 199	83	35 516	59 785	77 125	117
cars/1 000 inhab.	242	343	384	59				

Sources: IEA, 1990c, and country submissions.

Table III.21
Average Distance Travelled per Passenger Car in Selected IEA Countries
(km/car)

	1970	1974	1981	1986	1987	1988
Canada	19 281	15 367	19 430	15 700	17 244	n.a.
Western Germany	14 400	14 600	11 908	12 371	n.a.	14 600
Italy	12 021	13 000	10 461	11 500	n.a.	11 700
Japan	13 735	10 151	10 042	10 266	10 097	n.a.
Sweden			12 930[1]	12 550	13 110	n.a.
United Kingdom	14 831	13 800	14372	14 000	n.a.	14 648
United States	16 531	15 276	14 783	15 490	n.a.	15 900

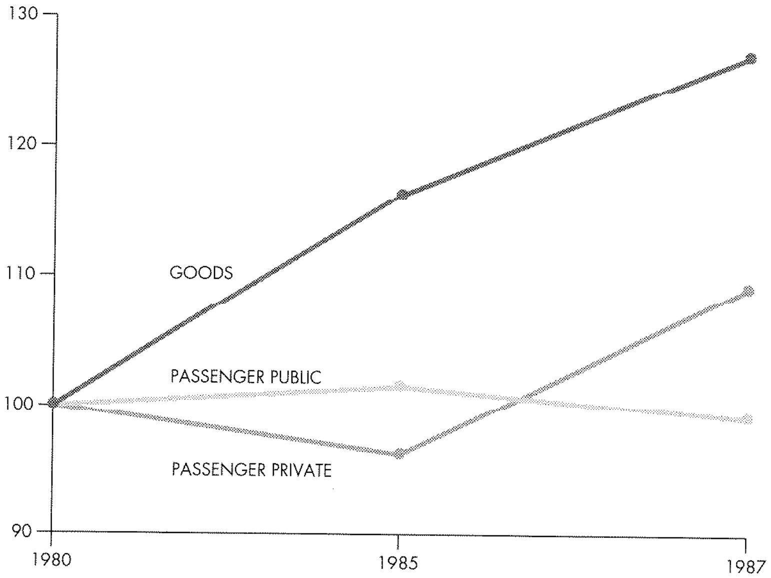
1. 1980 figures.
Source: IEA, 1991a.

took place more recently, from 1982 onwards. Though growth rates have been lower, the average level of motorisation is still highest in North America, with 554 cars per 1 000 inhabitants. There is a considerable range of car ownership levels in the IEA. Car ownership is strongly linked to purchasing power and economic growth, and European countries such as Spain and Portugal, which have been in the process of sustained economic growth for more than a decade, are experiencing high growth rates in car owership.

Another key determinant of energy demand for road transport is the average distance travelled per vehicle. Although relevant data, when available, should be considered as only approximate, some general assessments are possible. Table III.21, presenting estimates of the evolution of average annual distance covered by passenger cars in North America, some European countries and Japan between 1970 and 1987/88, shows large regional differences. Changes over time reflect both changes in individual vehicle use and in the number of vehicles per unit of population. The renewed increase in individual vehicle mileage in virtually all IEA countries between 1981 and 1986, despite the increase in the size of the fleet, indicates a more intensive use of motor vehicles as the price of oil fell.

This observation is supported by the analysis of passenger-kilometre and metric ton-kilometre data presented in Figure III.16. The growth in the size of the fleet of goods transport vehicles corresponds to a marked increase in metric ton-kilometres, which implies that the overall activity of this sector and the number of vehicles it uses have expanded. In the case of private cars, the increase in the number of vehicles is not matched by the

Figure III.16
Road Passenger and Goods Traffic, IEA (1980-1987)
(passenger-km and goods-km)



Excluding passenger and goods traffic in Australia, Ireland, New Zealand and Turkey and public passenger traffic in Canada.
Sources: ECMT, 1989, and IRF, 1989.

evolution of passenger-kilometres which remained stable until 1985 and has risen about 10% since then. This indicates that even if the fleet has grown and the distances travelled are greater, these increases are spread among a larger number of cars each carrying fewer passengers. The spread of annual vehicle consumption among European (1 167 litres/car/year), Japanese (1 297 litres/car/year) and North American (2 867 litres/car/year) passenger cars is related more to differences in the types and technical characteristics of cars than to distances driven annually. Figures for the public transport subsector (buses) show that its activity has experienced a relatively moderate growth and the increase in fleet size has not necessarily been accompanied by an increase in the number of passengers transported.

(c) specific consumption of new and average vehicles

The data on the fuel consumption of new vehicles presented in Table III.22 represent measurements drawn from the fuel consumption test procedures used in each country. The values derived from the various fuel economy test procedures are not strictly comparable among countries because of differences in driving cycles, vehicle selection and pre-conditioning, fuel economy measurement methods, etc. As a result, a comparison of the fuel consumption values shown in Table III.22 is potentially misleading. In addition, the trends in new passenger car fuel consumption illustrated are the result of several factors, including improvements in fuel-efficient technology, shifts in consumer preferences for fuel-efficient cars, the relative weighting of urban versus highway driving in the determination of combined fuel efficiencies and government regulations concerning safety and emissions.

Table III.22

Actual New Vehicle Fuel Consumption[1]

(litres/100 km)

	1973	1978	1979	1980	1983	1984	1985	1986	1987	1988
Australia	n.a.	11.80	11.20	10.20	9.50	9.45	9.50	9.30	9.40	9.10
Canada	16.50	13.10	11.40	10.30	8.48	8.51	8.49	8.38	8.28	8.10
Denmark	9.00	n.a.	n.a.	7.50	7.30	7.00	7.10	n.a.	6.80	n.a.
Western Germany	10.30	9.80	9.60	9.00	8.10	7.80	7.60	7.50	7.70	7.90
Italy	8.40	8.30	8.30	7.70	7.30	7.00	7.00	6.80	6.80	6.80
Japan	10.40	8.80	8.60	8.30	7.80	7.80	8.00	8.30	8.60	8.60
Netherlands	n.a.	n.a.	n.a.	n.a.	7.54	n.a.	7.15	n.a.	7.19	n.a.
New Zealand	n.a.	n.a.	10.50	n.a.	9.70	9.40	9.20	9.00	9.00	9.00
Spain	n.a.	n.a.	n.a.	8.70	n.a.	n.a.	7.40	n.a.	n.a.	7.40
Sweden	n.a.	9.30	9.20	9.00	8.60	8.60	8.50	8.40	8.30	8.20
United Kingdom	11.00	10.00	9.90	9.60	7.90	7.60	7.50	7.50	7.40	7.40
United States	16.50	13.10	11.59	10.00	8.91	8.74	8.52	8.37	8.28	8.20

1. The levels of efficiency (litres/100 km) cannot be directly compared because of differences in the test procedures, primarily between cars from different regions. Efficiency changes over time are unaffected by such disparities.

Source: IEA, 1991a.

Nevertheless, data collected in Table III.22 reveal an overall improvement in measured average fuel efficiency for new passenger cars. The most dramatic improvement took place in Canada and the United States, where passenger cars in 1973 were about 50% less efficient than in 1988. Though there was a marked narrowing of differences between 1973 and 1988, cars in North America are still usually less efficient on average than cars in Europe. There were two relatively distinct phases in the improvement in fuel efficiency of passenger cars over the period considered. The data presented in Table III.22 demonstrate that the early, stronger improvements in fuel efficiency in all three IEA regions can be related to a period of high fuel prices and the introduction of efficiency standards. As the price stimulus decreased after 1983, the rate of improvement can be seen to slow and even, in the case of Japan and western Germany, to reverse, as the composition of the fleet of new cars shifts towards a higher proportion of heavier, more powerful vehicles.

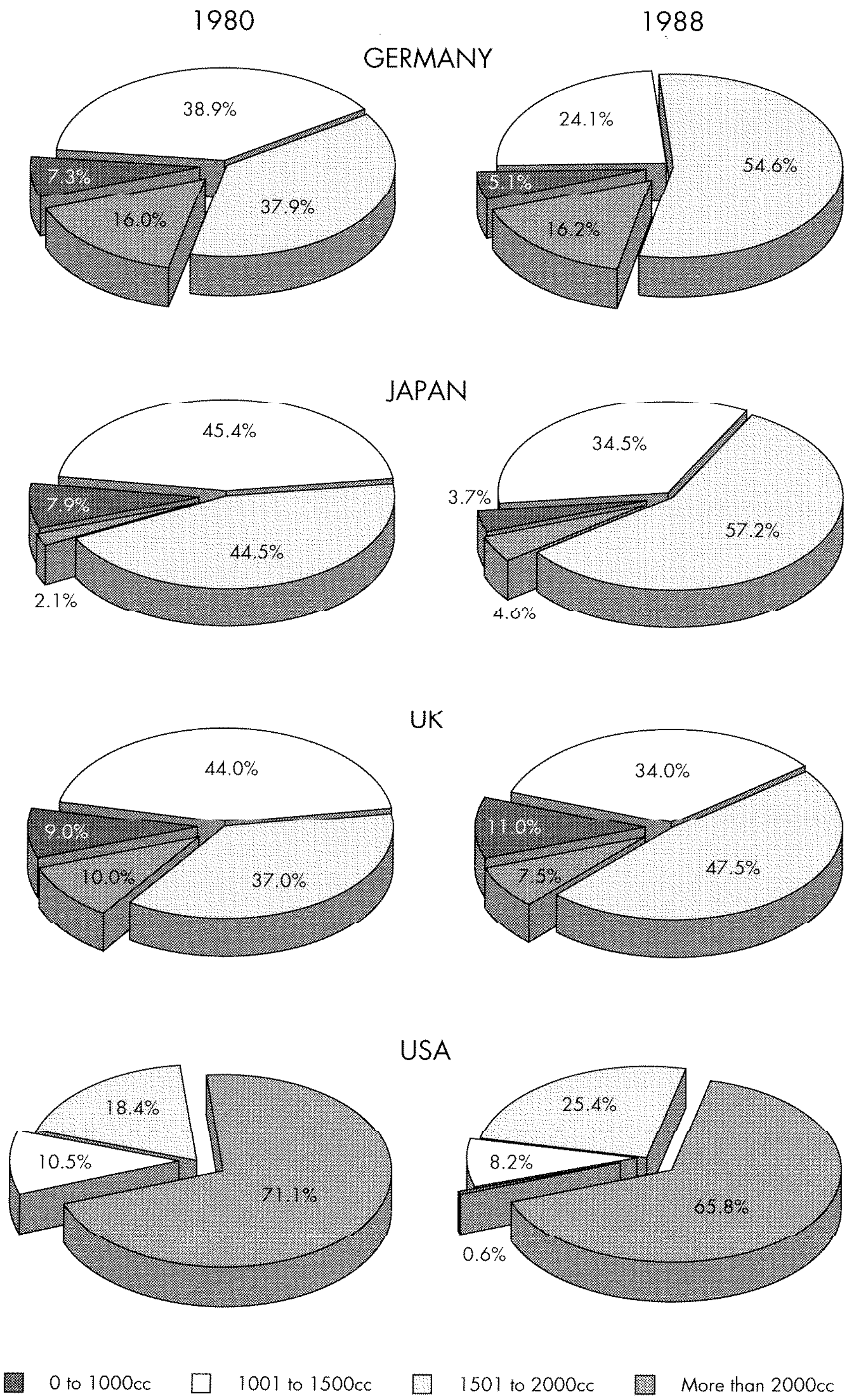
As new car fuel efficiency is a sales-weighted average of various types and sizes of automobiles, market shifts towards heavier or more powerful cars will inevitably decrease average efficiency. A 10% difference in body weight can account for a change in fuel consumption of about 5% and a two-litre gasoline engine typically uses nearly 50% more fuel than a one-litre one. Since 1973, there has been a narrowing of the spread of regional differences in vehicle weight. North American vehicles have progressively moved to a lighter category, while average weight has increased in other regions. Over 75% of the new car fleet in the United States consisted of cars weighing more than 1 200 kg in 1978, but only 54% of vehicles were in this weight category by 1982, and the proportion has remained relatively constant since. In Japan, on the other hand, sales of new cars weighing 1 266 to 2 016 kg more than doubled, from about 9% of sales in 1981 to 20% in 1986. In Sweden between 1985 and 1987, this category expanded from 12% to 13% of the total fleet, which itself grew 7% over these two years. North American vehicles are still, on average, heavier and have larger engines than the European and Japanese averages. In 1986, the average weight of a passenger vehicle in the United States was 1 380 kg, while in Japan that year less than 20% of new cars sold weighed 1 266 to 2 016 kg. In Sweden, traditionally a producer and user of some of the heavier European vehicles, 88% of passenger cars in 1986 weighed 1 399 kg or under (National Energy Administration, 1986).

Figure III.17 shows changes in the engine capacity of new cars since 1980 in four IEA countries. A shift towards more powerful cars — particularly in the category 1 500-2 000cc — can be observed in European countries and Japan. In the United Kingdom, average new car engine capacity rose from 1 430cc to 1 550cc between 1976 and 1989 (Potter, 1990). In the United States, the 1 500-2 000cc category has grown at the expense of cars in the range above 2 001cc, though there are indications that the shift to more compact vehicles has slowed recently with the renewed interest of consumers in larger models. At the same time that engines have been getting bigger, the specific power output per volume of engine capacity has also been increasing. For instance, the power output of cars in Europe was around 50 horsepower per litre ten years ago and is now in the range of 60 to 75 horsepower per litre (Amann, 1989).

Average fleet efficiency, shown in Table III.23, has not improved as rapidly as the figures for new cars would suggest, though the impact of improvements in new car fuel efficiency on the average fleet efficiency varies by country. In both Japan and western Germany, average new

Figure III. 17

New Car Registrations by Engine Capacity in Selected IEA Countries



Source: IEA, 1991a.

car efficiency improved by 30% between 1973 and 1986, while average fleet efficiency improved by less than 5%. In the United States, the improvement in new car efficiency was close to 50% and the efficiency of the fleet improved by more than 25%.

The difference between the rate of fuel efficiency improvement of new vehicles and that of the fleet as a whole is partly due to the fact that the average fuel efficiency of new cars is measured on the basis of test cycles and that average fleet consumption is calculated on the basis of actual consumption. It is extremely unlikely that the average driver in normal conditions will match new fuel efficiency levels determined in test cycles. In addition, higher energy use may result from individual behaviour, such as high speed and poor maintenance or driving skills. Furthermore, real vehicle use is now likely to involve a higher proportion of more energy-intensive urban driving, on increasingly congested roads. There is in any case a lag time in fleet turnover (on average, about nine to ten years), and the composition of the fleet changes over time as cars are retired and new cars brought onto the market.

The effect of changes in new vehicle engine capacity on the engine capacity characteristics of the fleet depends largely on turnover. Data from western Germany, Japan, the United Kingdom and the United States, shown in Figure III.18, demonstrate that the shift over the last decade towards more powerful cars is already affecting the overall characteristics of the fleet.

Table III.23

Average Fleet Fuel Consumption

(litres/100 km)

	1973	1979	1980	1983	1984	1985	1986	1987	1988
Australia	n.a.	12.00	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	11.80
Denmark	9.02	n.a.	8.60	n.a.	n.a.	8.80	n.a.	n.a.	8.50
Canada	n.a.	15.70	13.80	13.10	n.a.	12.43	11.84	n.a.	n.a.
Western Germany	n.a.	10.80	10.80	10.90	10.90	10.90	10.90	10.80	10.70
Italy	n.a.	n.a.	8.50	n.a.	n.a.	8.00	n.a.	n.a.	7.60
Japan	n.a.	11.80	n.a.	11.00	11.00	12.00	10.70	n.a.	n.a.
New Zealand	n.a.	11.70	11.50	n.a.	8.20	7.80	7.80	n.a.	7.90
Portugal	n.a.	n.a.	10.40	n.a.	n.a.	9.80	n.a.	n.a.	9.60
Spain	n.a.	9.50	n.a.	8.40	8.20	8.70	8.50	8.50	8.50
Sweden	n.a.	10.90	10.90	10.80	10.80	10.70	10.50	10.30	10.30
Switzerland	n.a.	n.a.	10.70	10.32	n.a.	9.30	9.20	9.10	9.00
United States	18.10	16.30	15.50	13.70	13.20	12.90	12.90	11.76	10.80

Source: IEA, 1991a.

By comparing the evolution of the three major factors influencing oil consumption in the road transport sector (number of vehicles, distance travelled and fuel efficiency), it is possible to assess the relative impact of each factor and how in some cases they have had

Figure III.18

Composition of the Fleet by Engine Capacity in Selected IEA Countries

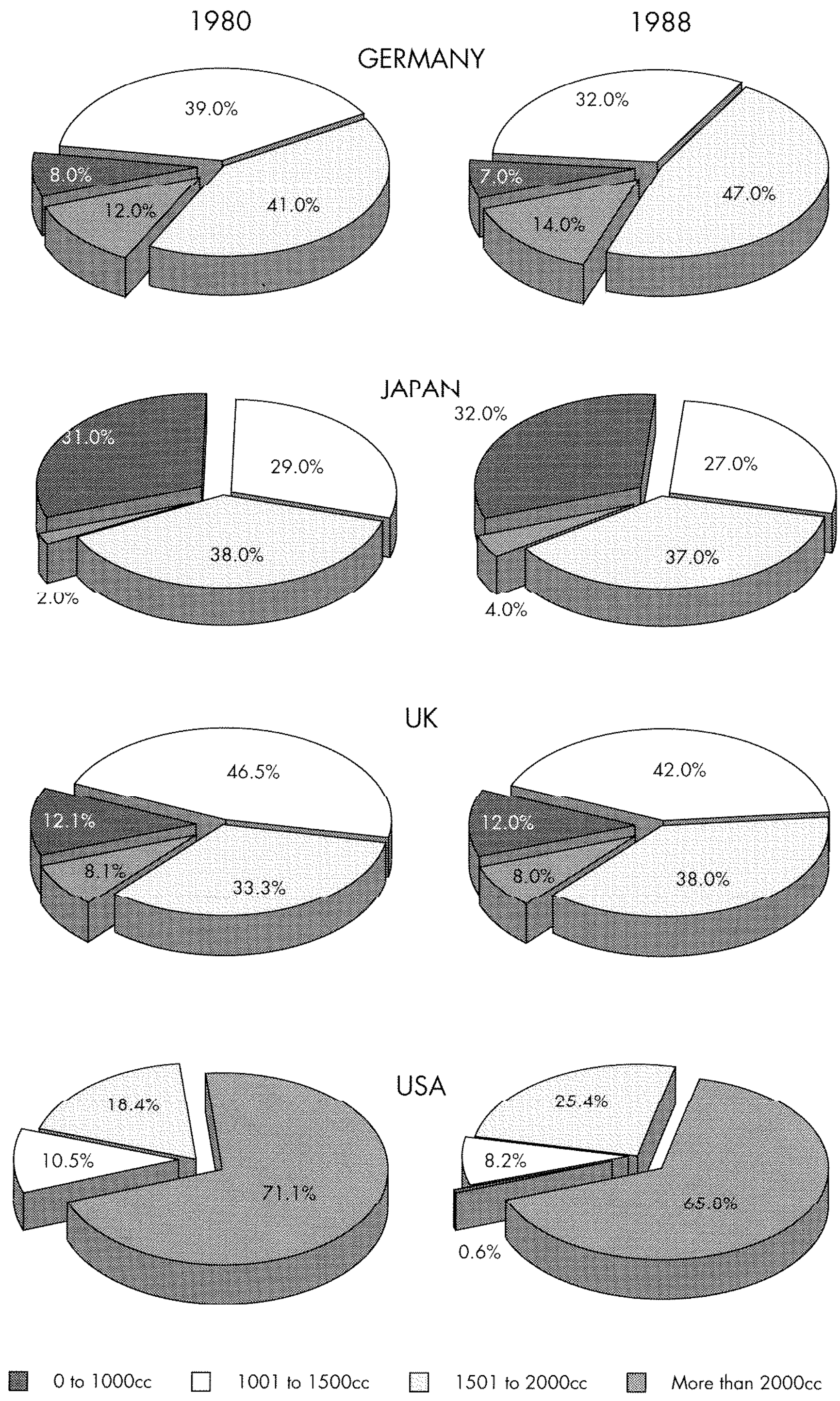
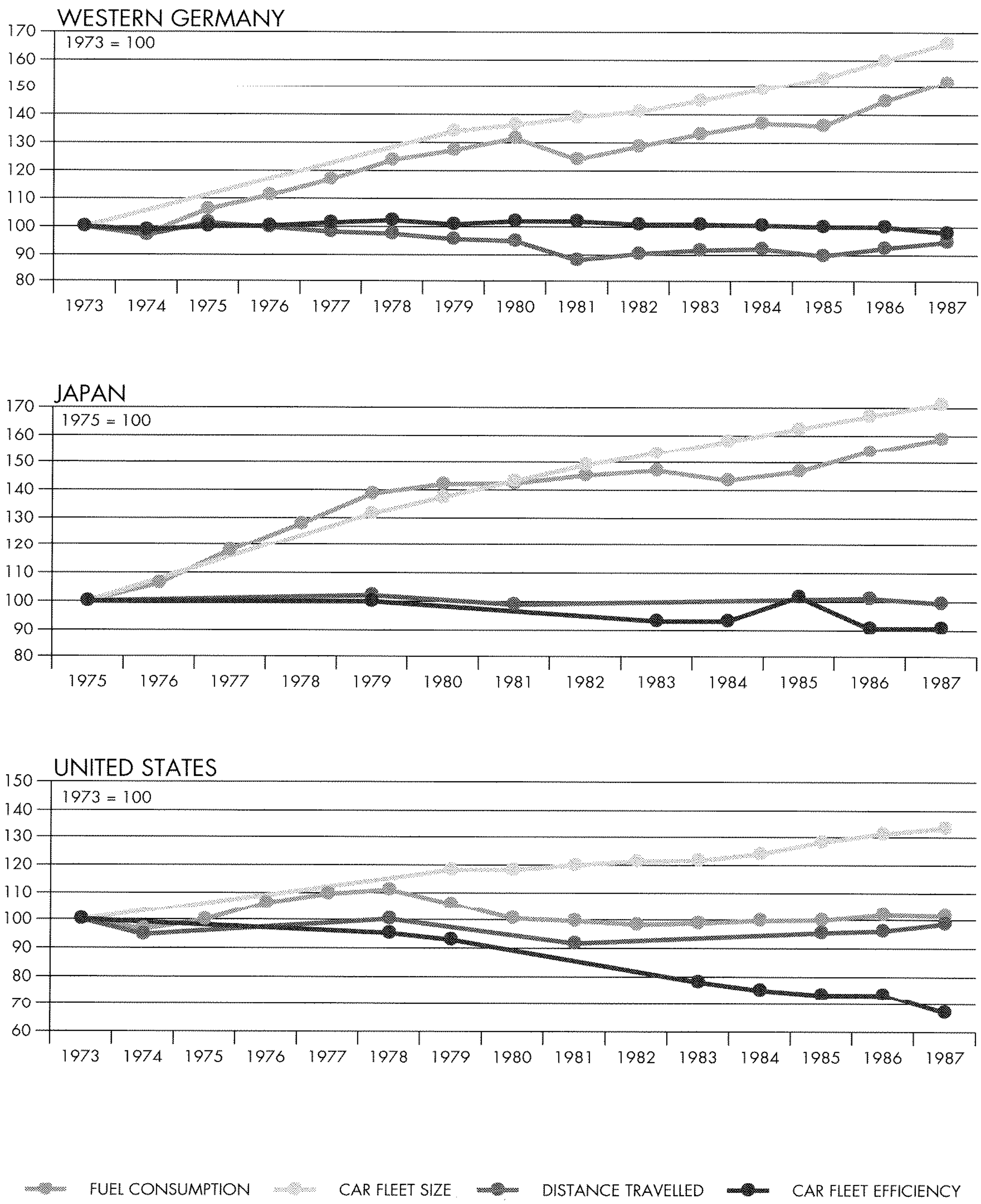


Figure III.19
Evolution of Factors Influencing Passenger Car Fuel Consumption in Western Germany, Japan and the United States



compensating effects on the increase in oil consumption for road transport. This analysis is illustrated in Figure III.19 in the case of the United States, western Germany and Japan, for passenger car gasoline and diesel consumption.

In western Germany, fuel consumption increased steadily from 1974 to 1980. This trend can clearly be attributed to the rise in the number of cars in use — even as the distance travelled annually by each car decreased slightly — and to the lack of improvement in fleet fuel efficiency. The price rises of the early 1980s coincided with a sudden fall in fuel consumption because of a temporary reduction in the intensity of use of the nevertheless growing fleet. But consumption resumed its growth as early as 1982 and accelerated markedly from 1985 as oil prices fell and both distances travelled and the number of cars increased.

In Japan, oil consumption increased steadily from 1975 to 1979, and again from 1984 to 1987, with relative stability in between. This pattern is mainly related to the growing number of cars in use and to the fact that improvements in fuel efficiency were offset by a trend towards larger and more powerful cars. In addition, there was some increase in the average distance travelled per car in 1985 and 1986.

In the United States, fuel consumption for passenger cars peaked in 1978, stabilised between 1980 and 1985, then started to increase again after 1986. In fact, gasoline consumption in 1987 was at about the same level as in 1973, in marked contrast to the situations in western Germany and Japan. While the car fleet increased, this was at first partly offset by significant improvements in fuel efficiency. The impact of distance travelled per car on gasoline consumption was mixed.

The precise impact of changes in the fuel economy of specific vehicles and of changes in average weight and engine power on average fleet efficiency can only be estimated in countries where data relating to these factors are available. In western Germany, available data show that the efficiency of new cars in the four categories of engine size (less than 999cc, 1 000-1 499cc, 1 500-1 999cc and more than 2 000cc) improved 20%, on average, between 1980 and 1988. If the engine size structure of the new fleet had remained the same in this period, the average new car fleet efficiency would have been 20% higher. In fact, because of a shift towards more powerful new cars, average new car efficiency improved only 12.2%, from 9 litres/100 km to 7.9. Preference for more powerful cars has therefore reduced the average efficiency of new cars by 7.8%.

Analysis carried out for the Netherlands (Bleijenberg and Rutten, 1990) by weight category shows that for any given weight, the efficiency improvement of new cars was 14% between 1980 and 1989, while the improvement in the average efficiency of new cars was only 8%. One reason is a 2% increase in the average weight of new cars, from 900 to 920 kg, resulting in a 1.5% loss in fuel efficiency. The remaining efficiency gap of 4.5 points is probably the result of a strong increase in the average engine power of new cars. A comparison of specific engine power (engine power divided by empty vehicle weight) and of vehicle weight reveals a remarkable increase of engine power of 25% for small cars and 15% for big cars. There is reason to believe therefore that preference for larger, more powerful cars in the Netherlands over the last decade has resulted in a 6% reduction in the average fuel efficiency of new cars.

All together, it is clear that early improvements in fuel efficiency have been offset by the growth in the size and intensity of use of the vehicle fleet. In addition, it seems that these efficiency improvements themselves have been adversely affected by the trend towards heavier and more powerful vehicles, particularly in the passenger car subsector. It therefore appears likely that this shift in consumer preference, along with the increase in the number of vehicles in use, has had a strong effect on the sustained growth of fuel demand in road transport. The majors factors that have acted on consumer preference, such as fuel prices and vehicle taxation, are examined below.

(d) factors influencing energy efficiency

Transport demand is determined by demography, economic activity and the need and desire for mobility. Understanding the influences and forces at work in determining energy demand for transport is further complicated by major measurement problems. Reliable data on energy demand and a better understanding of the many non-technical factors that influence energy demand are areas of relative weakness in many IEA countries. Indeed, it appears that the sector with the highest, fastest-growing oil consumption in IEA countries is the sector on which least data are available and where cause and effect relationships are least understood. This lack of information is an area of increasing concern, as it becomes clear that the energy efficiency and substitution opportunities successfully developed in other sectors have had little impact on the transport sector.

The major determinants of oil demand and of the average fuel efficiency of the vehicles that compose the fleet, such as the evolution of the size and structure of the fleet, its technical characteristics and its use, have been described above. Factors influencing these elements are related to the price of fuels, technical progress and the impact of transport or energy policies. In addition, though their relative weight is usually difficult to isolate, geographical differences or changes over time in fuel prices, fiscal policies and standards indicate that their impact on fuel efficiency or consumption levels can be significant.

As shown in Figures III.20 and III.21, there are major differences in gasoline and diesel prices and taxes within the IEA. Though most IEA governments use fuel taxation more to raise revenue than to encourage fuel efficiency, there does seem to be a certain degree of correlation between the levels of fuel taxes and prices and the average level of fuel efficiency of the car fleet. For instance, in the United States, where gasoline taxes and prices are traditionally the lowest in the IEA and where only a very small part of the car fleet runs on diesel, the average fleet fuel consumption (see Table III.23) ranks among the highest while Japan, with high gasoline taxes and prices, has a more fuel-efficient car fleet. However, in trying to understand how expensive gasoline appears to be to domestic consumers in different countries, the use of conventional exchange rates can be misleading. Differences in the cost of living also need to be taken into consideration. Figure III.22 compares the levels of gasoline prices in 1989 converted to US dollars using purchasing power parities.

In most IEA countries, fuel taxation favours diesel, though a few countries, such as Austria, Canada, Japan, Turkey and the United Kingdom, have a more neutral taxation approach. Only Australia, Switzerland and the United States have higher taxes on automotive diesel.

Figure III.20
Gasoline Prices and Taxes in IEA Countries (1989)

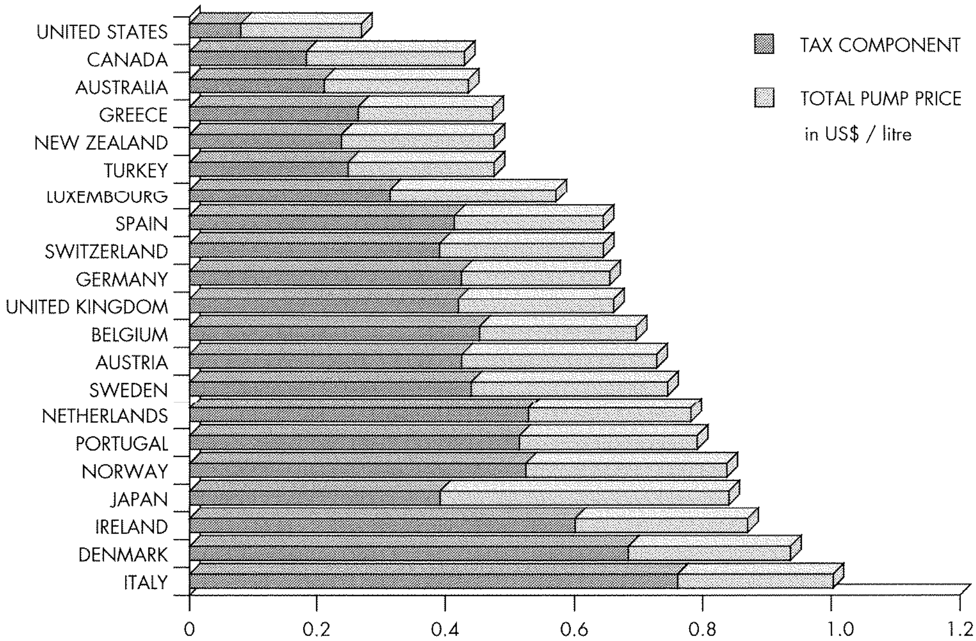
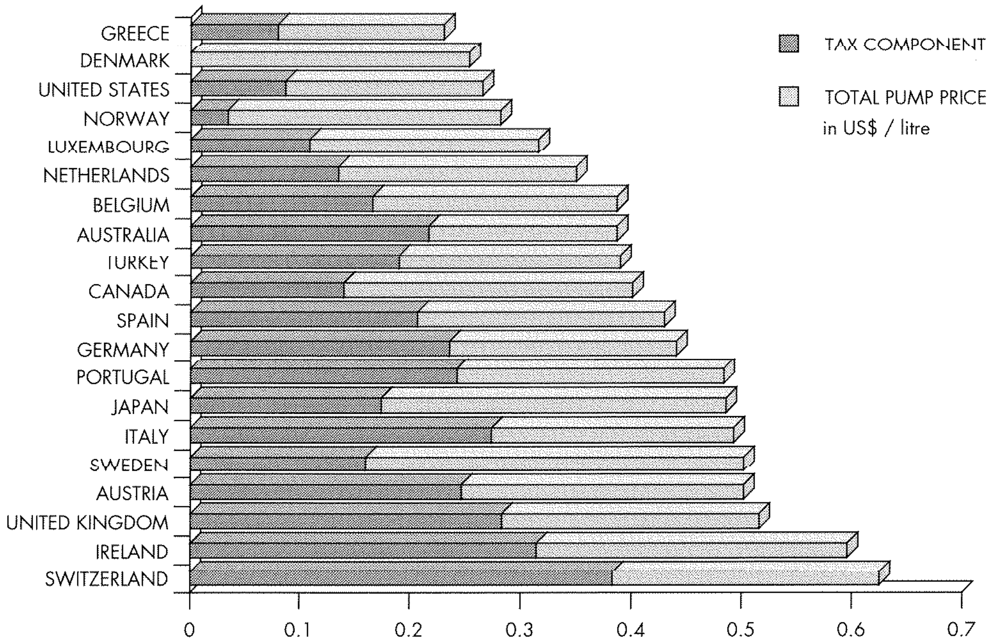


Figure III.21
Diesel Prices and Taxes in IEA Countries (1989)



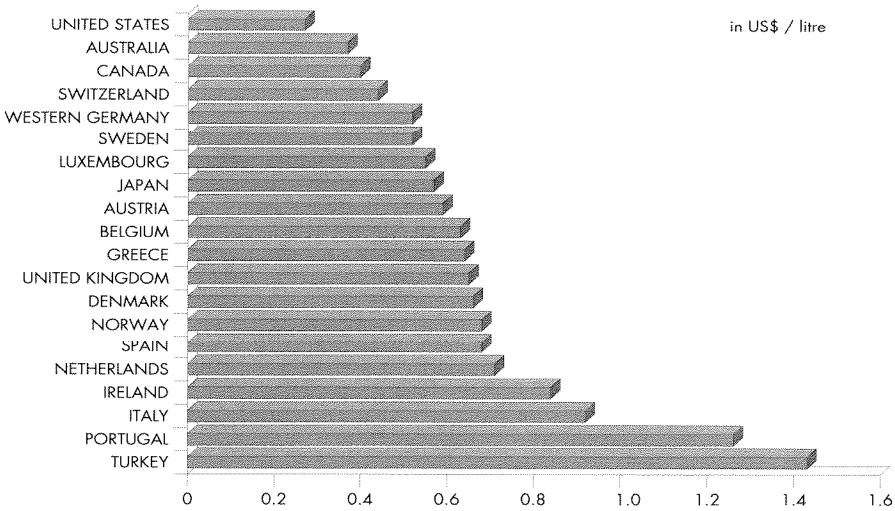
Note: In Norway, a charge based on mileage is also applied to diesel-fuelled vehicles.

Source: IEA, 1990b.

Figure III.22

International Comparison of the Price of Gasoline (1989)

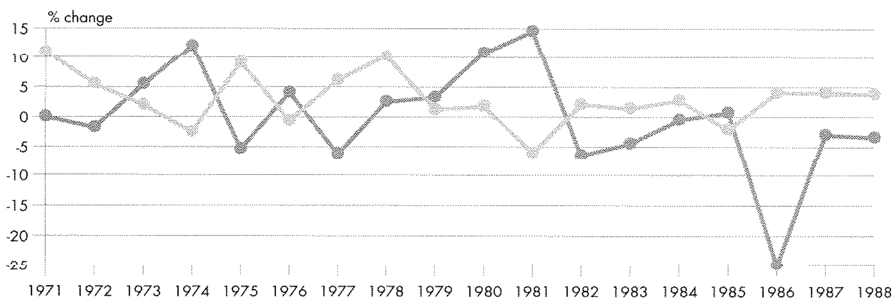
(using purchasing power parities)

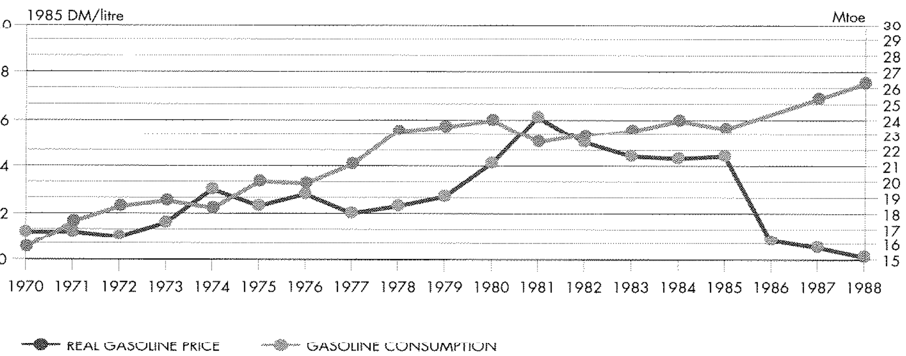


Source: IEA, 1990b.

Figure III.23

Changes in Real Gasoline Prices[1] and Consumption Levels in Western Germany (1970-1988)

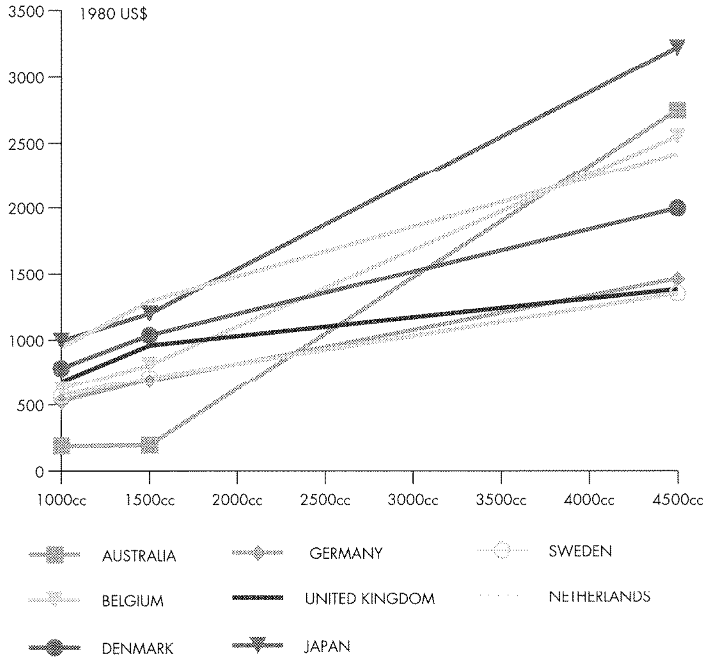




1. Price in 1985 DM deflated by Consumer Price Index.

Sources: IEA 1990a and b.

Figure III.24
Annual Tax Burden on Motoring
(fuel and vehicle taxes for private cars travelling 15 000 km/year)



Source: IRF, 1989.

In countries where the breakdown between passenger transport and goods transport for diesel and gasoline consumption is known, it appears that though increased activity in the goods transport subsector has caused an increase in diesel consumption, there have also been substantial shifts towards diesel in passenger cars (see Table III.9 above). Fuel taxation has obviously constituted an important market signal in the shift towards diesel-fuelled vehicles in countries such as Denmark, where there is a large difference between gasoline and diesel taxation (the pump price of diesel is a third of that of gasoline).

Price changes over time also indicate that, historically, real price increases have exerted downward pressure on demand and that demand has tended to expand as prices slackened. The relative magnitude of the changes is nevertheless variable and often quite different, as shown in Figure III.23 in the case of gasoline prices and consumption between 1970 and 1988 in western Germany.

Variable costs, including fuel costs, usually represent only a small part of the total cost of running a vehicle. However, fuel costs can represent a significant portion of the variable costs. Estimates presented in Table III.24 for passenger cars in the United States in 1988 show that fuel costs account for about 16% of the total operating costs, but 68% of the variable costs (based on 16 700 km per year). Figures for the United Kingdom show that fuel costs currently represent a similar share (16-20%) of total operating costs (Automobile

Association, 1990). The share of fuel costs for goods vehicles with higher mileages tends to be larger. In the United Kingdom, fuel costs for the heaviest goods vehicles are estimated to represent up to 25% of operating costs.

Table III. 24
Passenger Car Operating Costs in the United States (1988)

	US cents/km	% of Total Costs
Variable Costs		
Fuel	3.11	15.59
Maintenance	0.96	4.80
Tyres	0.48	2.41
Total Variable Costs	4.55	22.80
Total Fixed Costs (depreciation, insurance, finance charge, licence fee)	15.41	77.20
Total Operating Cost	19.96	100.00

Source: Davis et al., 1989.

The significance and impact of fuel prices depend largely on whether a journey is linked to an economic activity and whether the end-user is a company or a household. Fuel costs for transport operations carried out in the course of the production process are included in production costs. In the case of commercial transport, fuel costs are the only operating cost that can be readily reduced, unlike insurance or labour costs. This is not the case for private passenger transport, which tends to be defined in terms that are difficult to quantify, such as comfort or social status. In addition, account must be taken of delay effects: Some adjustments to changes in disposable income or fuel prices, for instance, may operate in the short term, acting on utilisation variables such as average distance travelled, rather than on longer-term trends such as fleet structure.

There is no straightforward correlation between the evolution of fuel prices and consumption levels because a large number of other factors are at work. They include the effect of vehicle taxation, which also varies markedly among IEA Member countries. Although these taxes are not directly related to fuel consumption as such, they have a real impact on consumer purchase decisions, as well as on the design of cars and on their fuel efficiency. The mode of calculating such taxes varies significantly among countries. For instance, Denmark, the Netherlands, Sweden and Turkey set annual car registration fees on the basis of the vehicle weight while other countries, such as Australia, Japan and Switzerland, use a combination of engine size and vehicle weight or of cylinder capacity and fiscal horsepower. As a basis for a comparison among countries, Figure III.24 presents examples from different IEA Member countries of the total burden of vehicle and fuel taxation for a passenger car travelling 15 000 km per year, and increases for cars with engine capacity of 1 000, 1 500 and 4 500cc consuming, respectively, 1 200, 1 500 and 2 700 litres of fuel per year to cover this distance.

Other factors include the impact of regulations, especially that of fuel efficiency standards for vehicles. In the United States, for instance, between 1973 and 1979 gasoline prices, after a steep rise in 1973/74, declined steadily in real terms until 1978, with annual consumption per vehicle falling 9.6%. In an equivalent six-year period, 1979 to 1985, starting from a lower base consumption, the fall in annual consumption accelerated to 14%, even though the real price of gasoline fell steeply after 1981. The difference between the rates of decrease of consumption per vehicle can be related to the introduction of the corporate average fuel economy (CAFE) standards in 1978. These standards probably played an important part in maintaining the momentum for fuel efficiency even when the price incentive declined, though it can be argued that US manufacturers would have continued to improve the fuel efficiency of their cars to compete with imported cars. At any rate, the United States is the only country that established mandatory fuel efficiency targets for new cars and light trucks. Other fuel efficiency programmes, in Australia, Canada, western Germany, Italy, Spain, Sweden and the United Kingdom, set voluntary targets and were the result of negotiations and agreements between government authorities and automobile manufacturers and importers. These programmes were nevertheless effective, with fuel efficiency improvements sometimes exceeding the initial voluntary target.

CHAPTER IV

SCOPE FOR ENERGY EFFICIENCY IMPROVEMENTS

On the basis of the analysis of historical developments presented in Chapter III, this chapter examines the scope for further changes and evaluates the potential for energy efficiency in the IEA up to 2005 and, to the extent that data permit, up to 2020. The first section discusses some of the major methodological issues involved in assessing energy efficiency potential. It also provides definitions and a brief description of the general method that will guide the assessment of potential in each of the end-use sectors covered in this study. This method is adapted to accommodate the characteristics and data limitations of each sector examined, as a very broad range of equipment types and users are analysed. Nevertheless, the method rests on the use of a common set of definitions throughout the analysis of end-use sectors, presented in sections 2.1. to 2.4.

1. METHODOLOGICAL ISSUES AND DEFINITIONS

The first step in evaluating future energy efficiency is to estimate the unit savings that technological changes could produce for a range of end-uses. In a second step, a broader evaluation extrapolates the technical potential per unit to all end-uses where the technological improvement is applicable. Simplifying cost and market assumptions are then applied to produce an estimate of the level of energy efficiency improvements likely by 2005. Finally, these estimates can be translated into demand reductions and integrated into energy demand scenarios, usually as part of a forecasting exercise. This process involves a number of major methodological issues, which are discussed below. They are central to any realistic evaluation of the way the market takes up energy efficiency opportunities.

1.1 Moving from technical to market potential: methodological issues

Estimates of future energy efficiency improvements and their impact on energy demand rest on assumptions about technical factors, equipment costs, expected market penetration rates and, most importantly, policy measures. Most of the methodological problems encountered in quantifying these improvements relate to the role of market factors, though there are issues that also need to be carefully considered in cases that appear to be less sensitive to economic factors, such as those defined purely by technological data. For instance, though an analysis may be limited to energy-efficient technology that does not affect the quality of service provided, some change is usually unavoidable.

It is essential to distinguish between the realm of technological achievements and the real world of consumers in order to gain a realistic picture of the potential for energy efficiency improvements under different market and policy conditions. Estimates of energy-efficient improvements that are intermediate between technical potential and market potential, such as zero life-cycle potential or cost-effective potential, are often meant to typify "ideal" situations. These estimates are basically analytical conventions that try to isolate factors such as technical achievement, costs, consumer behaviour and policy measures.

The definition of zero life-cycle potential is usually given as the energy savings achieved assuming zero life-cycle investment costs: The investment (or the marginal investment that produces capital flows from reduced energy costs) should be offset by the discounted value of energy savings over the lifetime of the equipment. While this approach is clear in theory, the actual calculation involves complex choices. First, it is assumed there is an ideal world where any investment that can be paid back over the lifetime of the equipment (however long it may be) will be made by consumers. Second, the calculation rests on forecasts of energy prices that are often unreliable. Finally, life-cycle costs critically depend on the choice of discount rates.

The definition of cost-effective or economic potential usually assumes an ideal world where producers and consumers follow in an economically rational way rules laid out in the analysis and adopt energy-efficient technology as soon as it becomes "cost-effective". A number of studies base estimates of the cost-effectiveness of energy conservation investments on a comparison between the cost of the energy saved and that of energy produced using the same discount rate (usually real discount rates of 6-10%). Where the cost of conserved energy is lower than the supply costs, the energy efficiency investment is considered cost-effective and it is assumed that the saving will be made by the consumer or even by the producer, through demand-side management programmes, for instance. The implication is that these levels of energy efficiency can be considered as policy targets, since they appear to be economically and technically achievable.

The concept of cost-effective potential can be misleading if it leads to the conclusion that equipment cost considerations (if they are known) can be isolated from other market factors and that no further costs need to be taken into account. In particular, the costs of the policy instruments needed to bridge the gap between the cost-effective potential and the reality of the market are not included. Yet measures to significantly change consumer behaviour in making decisions are likely to require fairly vigorous government action, ranging from financial inducements to regulation, and involve policy costs. These costs are real and should be incorporated into an overall assessment of "cost-effectiveness", along with governmental expenditure (including administrative costs) on, for instance, financial support schemes, as well as costs for consumers (including transaction costs) and equipment manufacturers of measures such as energy efficiency standards.

The evaluation of the cost-effectiveness of an energy efficiency improvement depends largely on the discount rate used, though there is no agreement on what represents an appropriate discount rate. In some cases, the discount rates applied to energy efficiency improvements are the same as those used by utilities for energy production investments; in other cases, premiums are included to take into account resource depletion, energy security and environmental considerations in order to create "societal cost-effectiveness" measures. Most individual (residential or transport) consumers make investment decisions without direct reference to discount rates and discounted capital flows. Even in commerce or industry, where investments are more likely to be evaluated in terms of rates of return or payback time, energy users are known to apply investment criteria that tend to be more stringent for energy conservation investments than for productive investments and those that increase their market share.

Therefore, if the concept of discounting is to be used to represent consumer behaviour, one should refer to implied discount rates that are calculated on the basis of the actual purchase behaviour of consumers. Most historical records of individual decisions on energy efficiency point to high implied discount rates — at least 35% — and, in some cases, as much as 200% (Meier and Whittier, 1983). Analysis carried out in the United States on the investment behaviour of consumers purchasing electrical appliances reveal implied discount rates for energy efficiency of 9-40% for air conditioning equipment (Hausman, 1979). A study of the willingness of consumers to invest in more efficient appliances carried out by the Department of Energy found implied discount rates as high as 279% (DOE, 1988). In addition, discount rates are highly variable from one consumer to another. For instance, low-income households in rented accommodation use much higher implied discount rates (usually above 100%) than owner-occupiers with larger incomes (Hartman and Doane, 1986).

As energy efficiency is often not a major consideration in the choice of energy-using equipment, any cost margins have to be paid back fast. Product characteristics are usually more important for individual consumers, as are productivity considerations for industrial consumers. In addition, investments in energy efficiency are subject to the fluctuations of energy prices, information on the performance of energy efficiency investments is often difficult to acquire and costs are usually sunk (e.g. wall insulation), which means that energy efficiency investments have a higher risk than many other business operations. These factors are all captured by steeper implied consumer discount rates.

The issues involved in understanding different perceptions of energy costs and benefits and translating them into discount rates and levels of cost-effectiveness potential underline the methodological problems in attempting to identify a single, absolute economic or cost-effective potential. Though applying discount rates of about 6-10% yields a certain level of a cost-effective energy efficiency potential, it is unlikely that this potential will be considered cost-effective by individuals or industrial companies. Substantial indirect or "hidden" costs can occur that consumers would ultimately have to bear.

1.2 Approach and definitions

The focus of the assessment of energy efficiency potential presented in this chapter is end-use equipment, rather than more general aggregates such as households. The energy efficiency of a household has no meaning because the services that energy performs within the household are many and varied. Industry and consumers do not buy energy as they might food, for direct consumption; rather, they purchase energy for the services that energy-using equipment can provide. This equipment has characteristics of energy use so that output per unit of energy use is measurable. This nevertheless poses some special problems, because the universe of equipment is far too large to deal with exhaustively in this or any other study. Accordingly, the range and type of equipment examined has been narrowed to represent the most important energy-using sectors and the most important energy services. For example, one energy service examined in the residential sector is refrigeration. The equipment that converts energy to that service is a refrigerator; for this type of equipment, it is possible to characterise refrigerators that represent the average stock in 1988 and refrigerators that represent the most efficient commercially available in 1988. Such prototypes and their characterisation are the basis of the examination of potential energy savings.

The practical obstacles to estimating energy efficiency potential tend to be amplified in the case of an assessment on an international level. Some simplification is therefore unavoidable. Very detailed knowledge is needed to quantify the scope for energy efficiency improvements for IEA Member countries in 2005 and 2020. These countries have different climates, industrial structures, income levels and market conditions. For instance, the calculation of the cost-effectiveness of a given energy efficiency improvement requires the incorporation of energy prices and costs; in dealing with 21 Member countries and three major end-use sectors, a rough estimation would involve about 300 different energy prices, to which one must add estimates concerning their future evolution. In addition, the price of energy-efficient equipment can vary considerably within each country and from one country to another, and if its market penetration increases, it is reasonable to assume that its price may change enough to affect the investment payback.

Two measures of energy savings potential are identified: the technical potential and the market potential. The use of the word "potential" suggests that these savings might be capable of being achieved but may not actually be achieved. It also suggests that these measures are being constructed with reference to some other measure, referred to here as baseline energy efficiency. Baseline energy efficiency is a measure of existing (1988) average energy efficiency levels, as described in Chapter III for each of the end-uses covered in this study.

The *technical potential* for efficiency improvements is the difference between a baseline measure and a measure of energy efficiency that takes into account the best technologies available, including some that are not commonly used for a variety of economic, technical or market reasons, as well as some advanced technologies that are expected to be commercially available and cost-competitive in the near future. Estimates presented in this chapter are based on a literature search and expert opinions solicited for purposes of this study. The variety of sources used means that a range of time frames (from present to 2020) are used.

The equipment costs associated with these technologies are also provided, insofar as they could be collected from the literature available. This information is essential in order to carry out a comparative analysis of the various technological options identified. The assessment of the technical potential for energy efficiency improvements is developed according to the sectoral end-use technologies listed in Table IV.1.

Table IV.1

Technical Potential: End-Uses and Technologies Assessed

INDUSTRY

chemical industry

biotechnology
catalysts
sensors and controls
separation systems
waste heat recovery

aluminium

carbothermic reduction
permanent/wetted anodes

iron and steel

iron making : alternative processes
steel making : alternative processes
direct casting

pulp and paper

improvements in pulping processes
recycled pulp
paper making improvements

cement

use of waste fuels
blending of secondary materials
kiln insulation

glass

monitoring and control
other technological improvements

food processing

process changes in separation and sterilisation
use of heat

engineering

use of process energy
space conditioning

cross-cutting technologies

waste heat recovery
combustion
separation
electricity use

RESIDENTIAL SECTOR

space heating and cooling

building shell and envelope
space heating and cooling appliances
carbon based
electric
air conditioning

water heating
lighting
refrigeration
cooking
washing machines

COMMERCIAL AND PUBLIC SECTORS

space heating and cooling

building shell and envelope
space heating and cooling appliances

lighting
office equipment

TRANSPORT

vehicle weight
aerodynamics
tyres, steering and suspension
transmission
electronics and engine management
engine type

The *market potential* for energy efficiency is the difference between a baseline measure of energy efficiency (taken to be 1988 average efficiency levels, described in Chapter III) and the average energy efficiency of the equipment used on the marketplace in the future. Many conditions will change between 1988 and the 21st century: energy prices, income levels, the availability and price of new equipment and the saturation rates of equipment in households and industry. Assuming that consumers take up available energy-efficient technologies implies that existing barriers to energy efficiency are overcome. This would require the implementation of policy measures such as those examined in Chapter V of this study. The market potential varies according to different combinations of market barriers and policy measures taken to overcome them. The analysis of the market potential is therefore inseparable from a thorough understanding of present market barriers. This contributes to a more realistic assessment of the way the market takes up technical opportunities to improve energy efficiency, on which, ultimately, practical policy recommendations can be based.

The differences between these measures of energy efficiency potential provide information about the direction and possible effect of policy measures designed to reduce emissions through improved efficiency. The difference between technical potential using advanced technology and baseline energy efficiency reveals the effect that technology improvement can have on energy use and emissions and the value of policy options that encourage technology improvement. The difference between market and technical potential using currently available technology indicates the role that economic factors play in the adoption of more efficient technology and the importance of the many other market factors that enter into the decision logic of consumers and producers. There are policy options and instruments that address the issue of the costs of new technology, the costs of energy that provide the service as well as consumer information and choice. The final measure, market potential, provides an indication of the uncertainties that surround any of these measures. These uncertainties suggest the need for a flexible set of policy measures that can allow the market to adapt as events unfold.

As indicated above, the measures of potential defined here are a simplification. In reality there is no such thing as an absolute "technical" or "market" potential, but a continuum from technological creativity to market opportunities and development. The approach described here is modified to take into account the specific nature of each sector, not only because technologies vary, but also because very different consumer categories have different perceptions of the costs and benefits of energy efficiency improvements. These differences, along with the market barriers specific to each end-use sector, will be explained as the end-use sectors are introduced.

2. TECHNICAL AND MARKET POTENTIAL FOR EFFICIENCY IMPROVEMENTS

2.1 Potential in industry

(a) technical potential

This section will first examine some of the specific branches within industry, such as chemicals and food processing, where the potential for substantial energy efficiency improvement exists. These branches tend to be those where energy represents a large share of total production costs (see Table IV.2). Then cross-cutting technologies that have broad applicability in many industry branches, such as the use of electricity and separations technologies, are addressed. From specific technologies, the discussion turns to equipment costs and to factors that prevent the adoption of technology and the achievement of technical potential. Market barriers and potential are discussed in the second section.

Table IV.2
Major Energy-Intensive Industries

Industry	Energy Costs as % of Total Costs
Aluminium	20-30
Iron and Steel	20-40
Cement	30-50
Gypsum	40-60
Glass	10-20
Synthetic Fibres	12-20
Paper and Board	25
Food Preparation	4-16

Source: Giovannini and Pain, 1990, p. 132.

i) chemical industry

Most basic organic and inorganic chemicals are intermediate in the production of other chemicals and involve two major steps, reaction and separation. Overall energy efficiency may be quite low even though each intermediate product is produced with reasonable efficiency. Each step may be interdependent from an energy point of view, so changing the energy requirement for one step may alter the energy balance for the entire process. Any fundamental process change that shortens the steps needed to produce a given chemical may have a significant impact on the energy requirements of a particular product. Such process changes might arise through improvements in catalysts/reagents, photochemistry or the application of biotechnology. More prosaic improvements in reactor design would also improve efficiency.

Biotechnology. Development of organisms that speed reaction times with less need for high temperature and pressure, enzymes that are fashioned to more effectively break chemical bonds, and bioreduction of toxic by-products are examples of how biotechnology will shape the future of the chemical industry, "possibly before the turn of the century" (Giovannini and Pain, 1990, p. 144).

Catalysts. The use of catalysts leads to improvement in product selectivity and yields in reactors, thereby reducing downstream separations requirements significantly. Catalysts increase chemical reaction rates at lower temperatures and pressure, with lower energy requirements. Much of the recent decrease in energy consumption is due to new catalytic processes. Three notable examples are zeolite catalytic cracking, low-pressure process for low-density polyethylene and the use of multimetallic catalysts in re-forming and hydrorefining. Zeolite catalysts are being extended from petroleum refining to petrochemical manufacturing and NO_x abatement. The low-pressure process for low-density polyethylene is said to reduce energy requirements to only 35% of those of the standard process (Fulkerson *et al.*, 1989a). Another example of catalytic reaction involves recovery of low concentrations of organic acids as by-products of fermentation and in pulp and paper waste streams. Catalysts can convert these acids to hydrocarbons, which are easily separated from fluid streams.

Sensors and controls. Improved process control is the only remaining route to cost reduction and product improvement in mature industries. In many industries, the largest single impediment to improved process control is lack of suitable or accurate sensors. Sensors in industry are used to measure temperature, flow, liquid levels, pressure and composition (charge, humidity, density, speed, etc.). Studies have been conducted that indicate that, should appropriate sensors be developed, potential energy savings of 5-20% are achievable for individual industries. Overall, energy consumption could be reduced 10-15% by development of a full component of sensors that would allow more complete use of automatic processing controls (Fulkerson *et al.*, 1989b, pp. 10-11).

Separation systems. In the chemical industry, 70% of capital and 80% of energy use is related to separation/concentration steps, with the remainder directed at reactions. Four major areas of improvement are needed: improved distillation, membrane separation, supercritical fluids extraction and freeze concentration. In distillation columns, increasing the number of trays per column and improving the control process can produce a 10% improvement in energy use. Membrane separation is replacing older, less efficient processes (cryogenic, pressure swing absorption) and improving product quality. Major areas of growth for membranes are industrial gas separation, processing aqueous waste streams and processing foods and beverages. The application of membranes in the chlor-alkali industry has reduced energy intensity 25% (Giovannini and Pain, 1990, p. 14). Promising supercritical fluids extraction applications are in separation of polymers, extraction of heat-sensitive organics and separation of lipids from proteins. Freeze concentration has been emphasised in three applications: treatment of hazardous wastes, concentration of fruit juices and purification of organic chemicals. Freeze concentration methods can be 50% more energy-efficient than other separation techniques and yield products of higher purity (Fulkerson *et al.*, 1989b).

Waste heat recovery. Among industry branches, the chemicals branch is probably the most sophisticated in its use of waste heat. Further improvements would involve optimal energy management (heat cascading, etc.). Still, existing energy costs could be reduced an additional 32-48% over and above the 43% improvement seen since 1974 in the United States (Fulkerson *et al.*, 1989a). In the United Kingdom, it is estimated that potential improvements in the distribution and generation of steam alone could save 8% of energy use by 2000, compared with 1980. Savings are also possible by improving the design of specific chemical complexes: A "best practice" ammonia plant would save 35% of the energy used in the average plant in the United Kingdom. Newer plants have achieved 20% reductions in energy use over older plants for other chemicals as well. In some applications, savings as high as 50% are possible through better use of waste heat and CHP (Energy Efficiency Office, 1984).

ii) aluminium

The Hall-Héroult process, developed in 1886, is still the basic reduction process for aluminium (using 12.9-17.6 kWh/kg). Alternative processes promise reduced electricity consumption, but none is yet commercially feasible. The Alcoa process (10-12 kWh/kg) suffers from corrosion problems; sulphide electrolysis (8.4 kWh/kg) creates unacceptable amounts of hydrogen sulphide. Several other process changes hold some promise for energy efficiency improvements in the future.

Carbo thermic reduction. Using a process similar to a blast furnace in ironmaking, aluminium could be directly reduced in an electric arc furnace. This process is not liable to see commercialisation, however, without substantial development. Even more exotic is the direct reduction of bauxite, moving directly from the ore to molten aluminium. Current practice now requires ore to be refined into alumina through pyroprocessing, then reduced electrolytically to aluminium metal. Direct reduction of bauxite would combine both steps, but again, significant development problems remain.

Minor changes that hold promise for efficiency improvements in aluminium production include permanent anodes and wetted cathodes. Permanent anodes would eliminate the problems associated with anode changes (cooling of the bath and solidification of the melt) as well as the energy-intensive use of coke to make the anodes. Wetted cathodes would save energy by reducing the voltage drop across the bath in which the aluminium is reduced. The development status of these improvements is uncertain (Fulkerson *et al.*, 1989a).

The major difference in energy efficiency of aluminium smelters is age: Newer ones produce a kilogram of aluminium with 13.5 kWh, older ones with 20 kWh. This compares with a likely evolution of 12 kWh/kg by 2000 and a theoretical limit of 6.5 kWh/kg. Recycling can reduce energy requirements 90-95%. In 1985, 26% of aluminium produced in Switzerland came from secondary fusion, that is, recycling (Giovannini and Pain, 1990, pp. 135-136).

iii) iron and steel

There are two major routes to the production of steel: The integrated process first converts ore to iron in a blast furnace, then decarburises the melt in a basic oxygen furnace; the alternative relies almost exclusively on scrap, melting and purifying it in an electric arc furnace. Two major technological advances, the EAF and continuous casting, account for the lion's share of energy savings in recent years. The use of EAFs, which are charged mostly with scrap, reduces energy requirements by about half from those of integrated steel production. But with increasing use of EAFs, there is a need for scrap beneficiation to remove residual elements. Several approaches hold promise: magnetic separation of shredded materials, vacuum processing, hydrometallurgical techniques, pyrometallurgical treatment using reactants and improved physical separation that is initiated where products (e.g. autos) are fabricated. Switching to CC from ingot casting reduces energy in steel finishing by half, and increases the product yield from 80% to 95%.

Efficiency improvements in US steelmaking could further improve more than 30% simply through integration of the latest technology into industry practice (Azimi and Lowitt, 1988). The major changes that would have to be made are dry quenching of coke, blast furnace modifications, in-process control of temperature and carbon content in BOFs, scrap preheating in EAFs, ladle injection and secondary refining, direct casting, direct rolling, slab heat recovery, and various secondary processing heat recovery techniques. These modifications would reduce energy use from 21.4 GJ/metric ton (1988) to 14.8 GJ/metric ton, an improvement of 31%, or a 16% improvement over Japanese production at 17.6 GJ/metric ton.

Ironmaking. Direct reduction of iron (DRI) would replace the use of blast furnaces and allow reactants other than coke, the production of which uses large amounts of energy and creates environmental problems. Currently, however, the combined energy use of DRI and EAF exceeds energy used in the integrated process. Several alternative processes, developed in Sweden, involve smelting partially reduced iron powder with pulverised coal using a plasma system (Elred and Plasmamelt) or submerged resistance heater. The major problem associated with these new processes is the high sulphur content of the iron.

Steelmaking. Direct steelmaking from ore, a concept similar to DRI, would continuously desulphurise and decarburise the melt until it would require only treatment in a ladle station before casting. The problems with this approach are similar to those with DRI: excess sulphur in the melt and a problem of heat transfer in the discharge of the melt. The approach offers the possibility of a 20-30% reduction in energy use, has production rates that are two or three times higher than those of a blast furnace and would be more economical than a BOF. This process could be commercially viable within ten years.

Ore-to-powder steelmaking converts ore to iron powder that does not require melting. One approach requires initial reduction, magnetic separation and chemical leaching. The product is dried, further reduced, then separated magnetically to produce a powder that can be rolled into steel products. The process is attractive because it uses 40% less energy and is less capital-intensive. The major technical barrier is lack of an effective magnetic separation technique (Fulkerson *et al.*, 1989a).

The plasma arc steelmaking process requires generating a stable arc between two electrodes. The very high temperatures generated in the plasma increase the heat transfer for melting scrap. The major advantage over the EAF is size: a plasma arc furnace can be constructed in the 5 MW range whereas an EAF takes 60-80 MW.

Direct casting. Traditional steel finishing requires pouring the molten steel into ingots, allowing them to cool, then reheating the steel for casting and rolling into semi-finished products, such as slabs, blooms and billets, which are converted into sheets and strip, bars, pipe and wire, and rails and heavy structural products. Continuous casting moves directly from BOF or EAF to the semifinished products, thus saving the energy required to reheat the ingot. Recent improvements in CC include thin-slab casting, thin-sheet casting and spray-form casting. Thin-slab casting produces a slab greater than two centimetres thick, so the rolling necessary to produce a thin slab is reduced. Full-scale production of this process is expected within three years. Thin-strip casting produces a strip less than two centimetres thick, and allows the hot rolling step to be eliminated. Oxidation and surface problems remain in the development of this process, however, and full-scale production is not expected for five to ten years. Spray-form casting deposits a spray of liquid metal onto a surface to produce a sheet even thinner than that produced by thin-strip casting. It also eliminates the hot rolling step and requires less finishing than the other thin casting techniques (Fulkerson *et al.*, 1989b).

iv) pulp and paper

Technologies and processes that were introduced before World War II dominate the pulp and paper industry. Fifty years of incremental improvements have made these processes quite energy-efficient and it is unlikely that major efficiency improvements can occur without fundamental process changes. Minor technological improvements, however, hold the promise for substantial energy efficiency improvements, in both the pulping process and the papermaking process. The three most promising advanced processes are biopulping, chemical pulping with fermentation and ethanol organosolv (organic solvent) pulping. All involve integrating a fermentation process into a conventional pulping process and derive much of their energy improvement from process integration and use of waste heat. None is yet near commercial development.

The US pulp and paper industry reduced energy intensity 36% between 1972 and 1985 through efficiency improvements and greater reliance on wood wastes and spent pulping liquor (Garrett-Price *et al.*, 1987). Additional efficiency improvements could reduce purchased energy consumption by a further 36%. Among the technological changes that could bring about these gains are greater reliance on continuous digesters and displacement heaters in pulping, improvements in spent liquor concentrations through upgraded evaporators or freeze concentration, spent liquor gasification, mechanical dewatering in the papermaking process, and increased co-generation.

Where the bulk of papermaking is done with imported pulp, as in the United Kingdom, there are still opportunities for energy savings, primarily during the papermaking and drying operations. Wet pressing, vacuum removal and dry-forming techniques in papermaking, and radio frequency equipment and waste heat recovery in the drying of formed paper, could lead to a reduction of more than 26% in UK papermaking energy use by 2000, compared with 1980 (Energy Efficiency Office, 1984).

Chemical pulping. The process that dominates in chemical pulping is the kraft (or sulphate) process, which produces an excellent, high-strength pulp, but the yield is only about 50%. Although it is a mature and highly optimised process, energy balances could be further improved 20-25% within the foreseeable future. More than half of the energy used is currently derived from recycled biomass wastes. Further improvements can occur with improved concentration of black liquor before combustion and heat recovery of molten salts after pyroprocessing (Fulkerson *et al.*, 1989a). The range of efficiency for the kraft process is

1.5-9 GJ/metric ton of air-dried pulp. Continuous digesters are the most efficient, since most batch digesters still use direct steam. However, indirect steam and displacement heating for batch digesters make them almost as efficient as continuous digesters. It is anticipated that US mills will continue to reduce intensity at the rate of 1% a year. Swiss industry will consume 83% as much energy per metric ton of pulp in 2005 as it did in 1985 (Giovannini and Pain, 1990).

Mechanical pulping. Compared to the kraft process, mechanical pulping provides a higher yield (near 90%), but fibre strength and colour are substantially inferior. Recent process changes have been towards chemical and thermal pre-treatments that reduce yield and electricity requirements but provide higher quality pulp and recyclable biomass. Enzyme pre-treatment appears constrained by thermodynamics (the chemical pathways by which this could be effective require more energy than current methods) and biological treatments involve the use of organisms that are pathogenic to commercial forests.

Recycled pulp. The energy consumption for making paper from recycled pulp is only about half that required by the kraft process. Progress is being made on using enzymes to remove ink and sizing from post-consumption recycled paper and to separate the fibres. The major stumbling block to effective integration of recycling remains a suitable post-consumption collection technique.

Papermaking. Improvements concentrate on better process control and on equipment that removes the water mechanically and allows greater speed on the process line. The major process innovation that allows removal of water from the pressed paper is the extended nip press. These presses allow the pressure on the paper to be increased and reduce energy requirements for drying. Extended nip presses allow energy savings of 15%-30% for papermaking and drying. These savings range from 5% to 10% for the entire process (Garrett-Price *et al.*, 1987).

The energy intensity of pulp- and papermaking depends on the process used to produce the pulp and the fraction of waste paper recycled. Energy intensity factors are reported in Table IV.3.

v) cement

In cement production, consumption ranges from 3.2 to 7 GJ/metric ton of clinker produced. A representative value for an old plant using the wet process is 6.5 GJ/metric ton, while a new plant using the same process is likely to produce a metric ton with only 5 GJ. An old plant using the dry process will use 4.2 GJ/metric ton, a newer plant 3.2. In 1975, the difference between the best and worst plants was 50% in Switzerland; now that difference is only 15%, some of which is attributable to differences in raw material quality. The fossil energy content of cement production can be reduced further by using waste fuels and blending the cement with secondary materials. It is estimated that 800 MJ per metric ton can be saved through further technology improvements (100 MJ/metric ton), use of off-grade fuels (300 MJ/metric ton), reduction of clinker firing temperatures (300 MJ/metric ton) and blending of secondary materials (100 MJ/metric ton) (Giovannini and Pain, 1990, p. 140).

Table IV.3
Energy Intensity Factors in Pulp and Paper (1987)

Country or Region	Percentage of Pulp[1]			Exported
	Chemical	Mechanical	Waste	
OECD Europe	59.3	33.4	37.3	5.3
United States	81.1	9.6	27.6	39.9
Canada	54.8	24.3	0.0	50.1
Japan	76.3	17.3	53.1	0.0

1. First two columns are per cent of new pulp; last two are per cent of total pulp.

Source: OECD, 199093-.

Technology improvements in the US cement industry could reduce energy use as much as 40% if all cement producers operated at the efficiency of the most efficient plants (Garrett-Price, 1985). These efficiencies could be achieved by improving the grinding of raw materials and clinker, the kiln, and the use of waste heat and waste materials (both in cement blends and as fuels)[1]. In the United Kingdom, median energy use in the cement industry in 1981 was 5.71 GJ/metric ton, of which 5.05 GJ was used in pyroprocessing. It was estimated that, by 2000, 29.6% could be saved by converting from wet to dry processes, kiln insulation could save a further 2%, waste material blends could reduce energy requirements 2.4%, mineralisers added before kilning could lower temperatures and cut energy use 3.3%, improved combustion control could save 5% and waste material as kiln fuel could reduce fossil fuel use 4.4% (Energy Efficiency Office, 1984).

vi) glass

In the US glass industry, efficiency improvements between 1972 to 1985 reduced energy intensity nearly 35%, and the potential for further improvement is quite large (Garrett-Price *et al.*, 1986). Efficiency improvements using the best available technology could range from 17% to 33%, while advanced technology available by 2000 could reduce energy intensity a further 37%. Energy intensity could decline by up to 50% if technology that will become available after 2000 is adopted. Since most of the energy used occurs in melting silica and other ingredients, most of the savings would occur here, through oxygen enrichment, batch preheating, improved refractories and process control.

In the British glass industry, 88% of the energy used was in melting and annealing, 7-10% in services and 2-3% in forming, the rest going to mixing, transport and administration. The range of energy use is quite large, with containers (69% of production) requiring 8.5-14.2 GJ/metric ton, flat glass (17% of production) 11.9 GJ/metric ton and other products (14% of production) 21-86 GJ/metric ton. Average consumption in the industry in 1981 was 14.75 GJ/metric ton, a near 30% improvement over a decade. Further improvements are

1. As fuels, waste oil, rubber tyres and municipal wastes are leading candidates; blend components include fly ash, blast furnace slag and cement kiln dust.

possible through improved housekeeping, monitoring and control (15% savings). Possible technological improvements include electric melters/boosters (35% savings), improved regenerator designs (3%), secondary regenerators (5%), improved forehearths (3%) and better annealing lehrs (5%). These improvements are expected to reduce energy use 15% by 2000 compared with 1981 (Energy Efficiency Office, 1984).

vii) food processing

Energy accounts for less than 10% of total costs in food processing, where it is used mainly for production of hot water and steam; motor power, including refrigeration; fabrication processes; and space conditioning and lighting (10% of electricity use in France in 1984) (Giovannini and Pain, 1990). Raw materials are the most significant cost factor in this branch, so they may take a higher position of importance than energy savings.

Major process changes in food processing include biotechnical means to reduce high moisture content in raw materials, improved separation processes (membranes, absorbing surfaces, freeze crystallisation) and improved sterilisation (ultraviolet, ionisation). Recent innovations that have saved energy are reverse osmosis in juices, beverages and starches; mechanical recompression of steam applied in concentration of fluids (milk, juices, alcohol) and in solid product drying (630 kJ/kg of water evaporated, an 80% improvement over other drying techniques); hydraulic processes for drying; the use of condensing and induction boilers; and steam production facilities jointly used for heat and power (Fulkerson *et al.*, 1989a).

In British food, drink and tobacco processing, the distribution of specific energy consumption varied widely in 1984. In grain milling, the average energy use for breakfast cereals was 0.3 GJ/metric ton. Soft drinks required twice this, while milk and milk products used 1.5 GJ/metric ton. At the other end of the spectrum, the malt and spirits branch used 28-60 GJ/metric ton, tobacco required 12-25 GJ/metric ton and biscuits used 5-13 GJ/metric ton. Because of the wide variety of products produced by these branches, potential energy savings are difficult to evaluate. It is estimated, however, that savings in the range of 20-40% could be achieved by 2000, with 25% a reasonable estimate (Energy Efficiency Office, 1984).

viii) engineering

Like food processing, engineering has such a wide range of outputs that it is difficult to characterise in terms of energy use and even more difficult to estimate potential savings. Despite this, a British study of this industry has identified a number of options for improving energy efficiency within the branches of engineering. Process energy could be improved by better insulation of metal heating containers and further heat recovery from exhaust gases from furnaces, ovens and paint dryers. Boilers could be improved through regular maintenance and improved controls and sensors. Space conditioning energy use, a substantial proportion of total energy use (30-80%, depending on the branch), could be reduced through measures such as improved insulation, discussed in more detail in the next section. Further improvements could occur with more efficient use of motor power and better maintenance to reduce air compressor leaks. Savings are estimated to range from 12% for some vehicle assembly to 17% for electrical engineering (Energy Efficiency Office, 1984).

ix) cross-cutting technology

All industries use energy, even though the fraction of costs devoted to energy consumption may be quite small. Waste heat recovery and combustion efficiency improvements are two major ways of improving the efficiency of energy use in most industrial activities. Separation technology accounts for a large share of energy consumption in industry, and improvements in this area would have applicability across a wide range of industry branches. Similarly, motors and lighting account for much of the electricity use in industry, so improvements in these areas could also contribute to improved efficiency. (Space conditioning requirements are included in the discussion of buildings in Sections 2.2 and 2.3 of this chapter.)

Waste heat recovery. About 25% of the energy consumed in US industry is rejected waste heat, about two-thirds of it given off as gas streams and 28% as water streams. The median temperature of gas streams is 114° centigrade (Fulkerson, 1989a, p. 109). Product cooling accounts for only about 4% of waste heat, but with high median temperatures that might economically be captured. The industries with the greatest waste heat are primary metals, food processing, pulp and paper, non-metallic minerals and chemicals. The major obstacle to waste heat recovery is a mismatch between process requirements and the reject streams. It has been estimated that the potential savings from waste heat recovery is 54-64% in the Netherlands, 36-50% in western Germany and 41-67% in Japan (Giovannini and Pain, 1990, p. 158). The three major techniques for capturing waste heat are heat exchange, CHP and heat upgrading using heat pumps.

High-temperature waste heat recovery is usually done with heat exchangers, using thermal storage to overcome the mismatch between time of need and availability. This energy cascading is usually cost-effective and the utility of the heat is magnified as it is cascaded to lower-temperature processes. In a US brick industry kiln, for example, heat exchangers with thermal storage reduced energy requirements by 45%. The CADDET (Centre for the Analysis and Dissemination of Demonstrated Energy Technologies) programme (IEA, 1988a) lists more than 15 pages of examples, primarily in Europe.

A heat pump is an effective method for upgrading low-temperature waste heat. The most widely used types are open-vapour recompression cycle, open-vapour recompression cycle with an evaporator and closed vapour-compression cycle. They are applied in food processing, which uses large quantities of hot water; industries that generate steam but do not recycle the feed water; and a variety of others. A popular application of dehumidifying heat pumps in Canada, for example, is in kiln drying of wood products (Strack, 1987). Significant progress has been made in the last five years in the search for more effective technology. Absorption heat pumps are especially attractive, operating at temperatures as high as 260°C and at temperature gradients as high as 90°C (Davidson and Erichson, 1987). The IEA sponsors a heat pump centre in Sittard, the Netherlands.

In industries with high demand for both steam and electricity — iron and steel, pulp and paper, chemicals — there are various alternatives and ample opportunity for CHP, such as cascading heat from combustion. Two examples of this approach are topping and bottoming cycle co-generation; in the former, a combustion turbine generates electricity directly and the waste heat raises steam that is used in processing. In the latter, steam is raised and used in processing, then waste heat is captured downstream to generate electricity. Either can improve processing efficiency 10-50% (OTA, 1983, p. 51). Using fuel cells to generate electricity directly could improve efficiency further (Blomen, 1989).

In industries with lower heat requirements, less potential for cascading exists, but other alternatives may provide substantial energy savings. Mechanical recompression of steam allows part of the energy in the steam to be recycled. Heat pumps can extract waste heat from the gas or fluid stream. A third option, used only in a few regions, is to apply waste heat to other uses, such as warming greenhouses or providing district heating for buildings (IEA, 1988a).

Combustion. Combustion uses a large part of industrial energy — as much as 70-80% of the total. Efficiency in combustion involves the conversion efficiency of fuel to heat (or directly to work) and the system efficiency with which that heat or work is used. The thoroughness of combustion and the transfer of heat from combustion gases to working fluids are the key factors.

A number of enhancements can both control the combustion process and alter the mix of emissions: magnetic and acoustic field effects, turbulence enhancement, catalytic injection, oxygen enrichment using membrane technology, pulse combustion and pressurised combustion. Even without such enhancements, a well-maintained combustor with the proper fuel-air mixing achieves nearly complete combustion. Improvements in this are related more to controlling oxides of nitrogen and sulphur than to achieving complete combustion (Fulkerson *et al.*, 1989b). The transfer of heat to working fluids is where more improvement could occur, through heat cascading, CHP and waste heat recovery. Examples of minor changes that can also lead to significant improvements in energy use are reported by the Energy Conservation Center of Japan (1989). In the case of the conversion of a furnace heating feed to a distillation column, the switch from manual to computer control significantly altered the performance of the combustion chamber. By selecting excess O_2 as the key operating parameter, they were able to reduce fuel requirements 1.2%. In another example, the use of forced draught fans at selected flues in a coke battery produced significant improvements in the oven and reduced both fuel and power requirements.

Separations. It is estimated that nearly 20% of industrial energy in the United States is used in separation processes. The most energy-intensive techniques are distillation, drying and evaporation, which in 1985 accounted for over 15% of total industrial energy use. By substituting newer separation technologies, 40% of the energy used for these three processes could be saved. The main alternatives are membranes, supercritical fluids extraction and solvent extraction, and leaching.

Membrane separation has the potential to substitute for distillation, evaporation and drying across a broad spectrum of applications, but practical and commercial applications are currently quite narrow. Membranes are used to separate some organic liquids in the chemical industry, to recover starches in the food industry and to recover lignin in the pulp and paper industry. These three examples alone have the potential to save 60 TJ per year. Their current limitations are that they work only in relatively narrow temperature and pH ranges, and that membranes are quickly attacked by organic solvents and corrosive gases.

Supercritical fluids extraction is conceptually similar to other forms of extraction but uses a solvent in a supercritical state. The advantage is that the solvent can be recovered simply by reducing the pressure or increasing the temperature and diffusion is much faster so phase transfer may be enhanced. Extremely tight process control is possible because small changes in temperature and pressure can produce large changes in the solubility of the material. Two current applications are the removal of caffeine with supercritical CO_2 and the destruction of organic compounds in waste water with supercritical water.

Solvent extraction and leaching separation techniques are broadly applicable to separation of both organic and inorganic materials. Their major drawback is that in some cases they necessitate an evaporation or distillation step to recover product and purify the solvent for reuse.

Electricity use in industry. The Electric Power Research Institute (EPRI, 1988) examined the potential for efficiency changes in electricity use in US manufacturing. Motor drive accounted for nearly 70% of 1987 industrial electricity use, process heat 8%, electrolytic processes about 13% and lighting about 9%. Most electrolytic processes occurred in the chemical industry (chlor-alkali is an example) and in primary metals, especially aluminium. Electricity is used for process heat mostly in primary metals and in the metals fabrication industries. Possible efficiency improvements were adjusted for capacity growth and equipment turnover. Efficiency improvements examined were high-efficiency and adjustable-speed drives for electric motors, methods of waste heat recovery including recuperators, efficiency improvements in chlor-alkali production (diaphragm and membrane cells), more efficient electrolysis in aluminium production and more efficient lighting technology.

Electricity intensity could range from 50% to 65% of 1987 levels to provide the motor drive requirements needed in the year 2000. Electrolytic improvements in chemicals and aluminium production could yield energy intensities that are 50-70% of 1987 levels for aluminium and 98% for chemicals (most chlor-alkali has already been converted to more efficient processes). Efficiency improvements could reduce energy intensity to 75-80% in process heating and 50-64% in lighting from 1987 levels. The study also examines the penetration of existing electrotechnologies that can substitute for fossil energy use or might be adopted because of process efficiency changes. They include ladle refining, freeze concentration, heat pumps, induction melting/heating, infrared processing and ultraviolet curing. The penetration of these electrotechnologies increases electricity use but reduces energy use, even taking into account the fossil fuel needed to generate the electricity. The results of this study suggest that 38.4% of "base case" electricity could be saved if the maximum technical savings were achieved. These savings would amount to about 9% of total industrial energy use and are in close agreement with the estimates of Lovins (1988 and 1989), if the repowering and rewiring savings are ignored.

Electric motors account for a large part of electricity use in industry. It is estimated that motors account for 60% of electricity use in Sweden and 70% in the United States. Motors drive pumps, fans, compressors, chillers and conveyors and are prime movers in mills, kilns, machine tools and robotics. The potential for savings by using high-efficiency and adjustable-speed drives ranges from 5% to 50% (Giovannini and Pain, 1990, p. 35). Potential savings of 32% are possible for improvements in the whole drive system, based on the service required and including improvements in the supported equipment, such as pumps or refrigerators (IEA, 1989).

(b) market barriers and potential

Though it is generally recognised that the industrial market for energy-efficient equipment is less subject to market barriers than other end-uses, a number of significant barriers prevent penetration of energy-efficient equipment in the industrial sector. Foremost is the lack of information about availability and reliability of new equipment. Other important barriers include a separation of expenditures and benefits; limited capital; rapid payback requirements dictated by investment opportunities elsewhere; the impact of electric and gas tariffs; lack of interest in peripheral operating costs; and legal and administrative obstacles (Grubb, 1990).

Lack of knowledge. Small and medium-sized companies, especially, may know little about the opportunity for energy savings and may lack skills to achieve them. Evidence indicates that such lack of knowledge is pervasive. Even in large firms where energy costs are a small fraction of total costs, this lack of knowledge prevails. A lack of awareness or concern about energy efficiency may be a rational management choice, given the array of concerns; however, evidence from a variety of programmes suggests that there is substantial opportunity for energy savings through focused information programmes.

Separation of expenditure and benefit. The individual in a firm most aware of the opportunity for energy savings is the plant engineer or the energy manager. Within their purview are minor changes in the way the plant operates, purchases of energy and non-energy materials and decisions about the use of the labour force. Their actions are usually constrained when changes require major capital expenditures, which are generally decided by corporate headquarters. The plant manager may fail to get corporate approval for the capital expenditure required.

Limited capital. Capital can be raised through equity or debt flotation. The tax treatment of these options may make one form more attractive, but all come at a cost. Sometimes the cost has less to do with direct borrowing costs than with the perception of the debt-asset ratio, which is an important consideration in evaluating a firm's performance. Once finance is assured, the highest rate of return to assets is obtained by ranking investment projects against available capital. The investment attractive to the plant manager may not clear the hurdles established at the corporate level, which take these constraints into account. In a small or medium-sized firm, access to capital, which is more severely limited, is an even more important consideration.

Rapid payback requirements. Rapid payback of investment would be expected in a regime of high capital costs, but other factors could also give rise to this need. If an internal rate of return is as high as 20%, not unreasonable in many industries, an energy-efficient investment would have to have a payback period of under four years to provide the same return as on currently held assets. Investment opportunities other than the acquisition of further assets may provide higher returns than those obtainable through energy efficiency. The risk associated with investment in energy efficiency, whether real (as when newly purchased equipment must be integrated into the operation for the first time) or perceived (the fear that claims for energy savings may be overstated) may increase the rate of return required.

Energy tariff structures. Most gas and electricity pricing includes a fixed component of costs and a variable component. The former covers fixed operating costs and amortisation of capital expenditures while the latter covers variable operating costs, such as that for fuel to produce electricity. While this way of pricing is usually applied to households and commercial clients, there is an industry counterpart in block rates based on usage, where rates decline as use increases. A firm's capital expenditures to save energy will normally apply only to the variable component or, in the case of block rates, only to the marginal block, not the fixed part or higher tariff blocks. Such pricing is unlikely to encourage capital outlay on energy savings. In addition, in some cases electric utilities have been encouraged to sell power to large consumers, such as aluminium smelters, at lower rates, which has tended to encourage the increased use of electricity.

Lack of interest. Most of industry is not energy-intensive. With the exception of the industry branches identified at the beginning of this subsection, energy in most branches accounts for 2-5% of total production costs. In the United States in 1980, for example, energy costs in textiles and wood products averaged slightly more than 3% of total costs. For other branches, such as printing and publishing, equipment manufacture, fabricated metal products and miscellaneous manufactures, energy costs were 2% or less of total costs. It is the nature of management to focus on problems; if labour costs are 70% of the total, more attention will be directed to efficient use of personnel than to efficient use of energy. When suddenly rising energy prices call management's attention to energy costs, then changes are made, though later the focus may be directed to other pressing problems. Even in industry branches where the overall savings in energy could be very large (e.g. the US automobile industry), other costs so dominate management attention that sustaining interest in energy savings is difficult.

Legal and administrative obstacles. In addition to legal obstacles such as discriminatory tax regimes or contract limitations, administrative policies and procedures may hinder efficiency improvements in industry. Block tariffs and capital rationing are included in this category, as are attempts by energy suppliers to reduce prices when company action threatens to reduce energy consumption substantially. The regulatory framework of utilities may limit opportunities for demand-side management initiatives if these result in a loss of revenue, for instance.

The equipment-based information that would allow the cost of achieving market or technical potential to be estimated is generally not available in IEA countries. There have, however, been a number of studies that attempt to estimate the costs of achieving some measure of potential and to examine the market potential for industrial energy efficiency improvements. A study by Cheng, Steinberg and Beller (1986) provides estimates of efficiency improvements to 2050 for the United States and the rest of the world. The technique used is to forecast energy demand to 2050 without technology improvements, then repeat the procedure assuming the introduction of new technology. In the industrial sector, the major technologies considered were process heat recovery, process flow optimisation, improvements in efficiency of fossil-fuel combustion equipment and improved motor drives. Forecasts to 2050 were developed from the Edmonds-Reilly model, with energy use for each service demand assumed to maintain a constant share over time. The introduction of new technology over 75 years saves about 70% of the fuel used in process heat, about one-third of the electricity for motor drives and electrolytic processes, and about 75% of the fossil energy consumed in steel production. Converting these savings to an annual rate and applying it from 1988 to 2010 suggests that energy used in process heating could be reduced 40%, electricity use would decline about 17% and energy used in steelmaking would fall about 47%.

A novel element of this study is the calculation of the costs of achieving improved efficiency. Using an average for heat recuperators (as a typical energy savings technology) the estimated capital costs are $2.51 per GJ per year, in 1980 constant dollars. The cost of achieving all the industry savings is calculated as $140 billion, with a return from fuel saved of $53 billion per year, i.e. a return on investment that averages 44.2%. Rescaled to cover only the period to 2010 and evaluated in 1988 constant dollars, this investment for the United States alone would be $89 billion and for the entire world, $874 billion.

In Canada, an independent study by Robinson (1990) looks generally at the sectors and end-uses where the potential for efficiency improvement is strongest. In the industrial sector, the two end-uses considered are process heat and mechanical drive. In the first, heat recovery and improved heating systems through insulation, energy cascading, advanced heating systems and co-generation have the potential to improve efficiency 32%. Mechanical drive efficiency could be improved 22% by variable speed drives, more efficient motors and better linkage systems for motors. Process heat uses about 69% of total energy in the industrial sector, which was 2 553.5 PJ in 1988, with specific end-uses of electricity accounting for the remainder. Industry accounts for about 36% of total energy use and about 37% of carbon emissions. With the changes outlined above, industry energy use would increase only about 8% from 1988 to 2005 and carbon emissions would actually decline 8%.

A further estimate of the potential for energy efficiency improvements in industry is provided by an analysis of data from Energy, Mines and Resources Canada's 1984-1986 energy audit programme, which focused primarily on small and medium-sized firms (Hoen and Kennedy, 1988). The data include over 400 energy audits, of which only 26 were classed as large. For all firms, the opportunity for energy savings was 11.2%, with a higher rate, 16.4%, for small and medium-sized firms. Since these audits do not include major equipment changes, they are indicative of the savings that were available at the time from improvements in housekeeping, insulation, etc. The major savings, according to these audits, are to be found in primary metals, chemicals, and pulp and paper, just as in the United States.

The major drawback to using these or similar studies to estimate costs for achieving potential for OECD countries is threefold: They do not reflect the dramatic changes that have occurred over the last eight or ten years; they do not take into account relative efficiencies or resource endowments; and they are not technology-based — i.e. drawn from estimates of costs of equipment. The changes of the past decade have not been minor: The world iron and steel industry has been virtually restructured, multinational chemical firms have rationalised production by establishing plants at least-cost locations and efficiency gains in other energy-intensive industries have been consolidated. These factors clearly need to be taken into account before estimating the costs of achieving levels of potential. The economics of the choice of equipment must include resource endowments because the logic of choices of equipment will be affected by their scarcity or abundance; the logic that may apply in a resource-rich environment is inapplicable elsewhere.

The most significant of these stumbling blocks is the lack of information on equipment costs. Indeed, one major finding of this study is that equipment-based cost data are simply not adequate for the task at hand. Although some countries are collecting this information for some industries, the sample is too small and not widely enough distributed among countries to allow for generalisation.

2.2 Potential in the residential sector

As noted in Chapter III, to assess the scope for further efficiency improvements, it is useful to distinguish between energy use for space conditioning and for appliances. The room for improvements in each category is influenced by significantly different factors that affect the extent of efficiency improvements that can be achieved as well as the time frame in which such improvements can realistically be made.

Efficiency improvements in space conditioning are generally achieved by changes in the building shell, such as better insulation, for which technology is available and readily identifiable. However, the turnover of the building stock takes place over several decades and, especially in Europe, new buildings are usually additions to the existing stock rather than replacements of old stock. Improvements in building shells are usually made in new buildings rather than existing ones, where better wall insulation or windows with low heat transmission coefficients can be very costly. Therefore, though the technical potential for energy efficiency improvements in heating and cooling end-uses might be substantial, savings are limited by the slow turnover of the building stock.

The second category, household appliances, covers a range of diverse technology, from light bulbs to stoves and television sets, for which technological improvements can be translated much faster into energy demand reductions because the rate of stock turnover is rapid. The average lifetime of household appliances ranges from one year or less in the case of incandescent bulbs to as much as 15 years for refrigerators and washing machines.

Table IV.4 shows the structure of energy requirements in the residential sector for Norway and Japan, broken down into major end-uses. Requirements for space heating hold by far the largest share of residential energy use. In Norway, about 64% of residential energy is used for space conditioning, hot water supply uses about 14% and lighting about 6%. Cooking requires about 3% and washing machines and refrigerator/freezers together account for about 4%.

The assessment of the technical potential for energy conservation in the residential sector presented in this section examines energy efficiency measures that can be applied to the following categories of end-uses: space heating and cooling, water heating, lighting, refrigeration, cooking and washing machines.

Table IV.4
Structure of Residential Energy Use

	Norway		Japan	
	(Mtoe)	(%)	(Mtoe)	(%)
Heating	2.21	64.1	10.50	27.9
Air Conditioning	—	—	0.46	1.2
Hot Water	0.49	14.2	14.46	38.3
Lighting	0.22	6.4	1.61	4.3
Cooking	0.11	3.2	n.a.	n.a.
Refrigeration	0.07	2.0	2.27	6.0
Washing Machines	0.06	1.7	0.13	0.3
Other Appliances	0.29	8.4	8.27	22.0
Total	3.45	100.0	37.7	100.0

Source: Country submissions and Koga et al., 1990.

(a) technical potential

(i) space heating and cooling

Space conditioning is provided mainly by gas, oil and, for cooling and ventilation, electricity. Historically, there have been substantial shifts in the fuel pattern, resulting from price differentials as well as increases in disposable income, which have fostered the introduction of fuels providing greater comfort. For example, in western Germany in 1989, oil provided 44.8% of heating requirements and gas about 30%, against 51% and 20% in 1980. Solid fuels supplied only 8.2% of heating energy requirements in 1989, a 13% decline from 1979 levels. In Italy, oil use for space conditioning decreased from 53% in 1980 to 45% in 1987 (Schipper, 1988). Available data for IEA Member countries show that 31% of total IEA heating and cooling demand is met by oil, about 43% by gas and over 11% by electricity (see Table III.5).

Space heating and cooling requirements are basically influenced by the thermal efficiency of the building shell (wall insulation, draught reduction), the conversion efficiency of appliances (burners, distribution system) and behavioural/operational patterns (such as desired temperature for certain rooms). The impact on energy demand of measures to improve efficiency in each of these three categories largely depends on the existing state of building insulation, on the climate and on occupants' habits. These characteristics also influence the economics of retrofitting. Although the technical potential for efficiency improvements is large — good building design together with heavy insulation can greatly reduce energy demand for heating and cooling — energy efficiency achievements in practice are limited by a variety of factors. Measures for dwellings that are continuously occupied may be advisable from a economic point of view, but they may be inefficient under certain country-specific conditions. The assessment of the market potential carried out in the second stage of the analysis has to take such conditions into account.

Building shell or envelope. The thermal efficiency of buildings is determined by the level of insulation and air infiltration, the size and characteristics of windows and the orientation of the building. Measures to improve thermal efficiency include special design, heavier insulation, double or triple glazing and the sealing of cracks. Table IV.6 presents energy requirements for heating in 1988 for countries where data are available. It reveals substantial differences in energy requirements for heating per square metre, ranging from 167 to 333 kWh/m^2 per year. Climatic variations and differences in insulation levels and average dwelling size explain these disparities. For example, the average dwelling size in Canada is 160 m^2, in Italy it is 90 m^2 and in Japan it is 110 m^2. Table IV.5 also shows that energy use for space heating in new buildings is generally much more efficient than in existing buildings, though there are exceptions, such as Sweden.

Table IV.5

Energy Requirements for Space Heating (1988)

(kWh/m^2/year)[1]

	Existing Dwellings	New Dwellings
Austria	333[2]	n.a.
Canada	219	n.a.
Denmark	194	120
Ireland	210	130
Italy	167	n.a.
Japan	134	n.a.
Norway	250	185
Switzerland	n.a.	130
Sweden[3]	209	207
United Kingdom	267	222
United States	202	152

1. Data are not corrected for climatic variations and refer to gross heat consumption.
2. 1986 data.
3. Including water heating.
Source: Country submissions.

Options for reducing heat losses vary according to the location of these losses. For an average detached building in a temperate climate, about one-third of the losses occur through the walls and roof and about 10% through the windows as well as through ventilation. There are also considerable differences in the energy intensity of single- and multifamily houses, as shown in Table IV.6 for Norway.

Table IV.6

Energy Intensity in the Norwegian Building Sector

($kWh/m^2/year$)

	1980	1988	2005	2020
Single-Family	233	247	220	200
New SF	170	180	160	140
Multifamily	253	272	250	230
New MF	191	206	185	170

Source: Country submission.

Energy requirements for space heating can be influenced by measures that focus on the characteristics of the envelope, by energy gains from internal and external sources, by improved efficiency of the heating system and by behavioural changes, such as temperature reductions for the whole dwelling or certain rooms. Passive solar energy, heat pumps, high-efficiency windows and development of a building's heat storage capacity can substantially reduce energy consumption for space conditioning. Passive solar houses are technically possible even in harsh climates (Giovannini and Pain, 1990), though economic considerations and certain building regulations prescribing thermal and technical characteristics limit the introduction of such houses to specific niches.

Table IV.7 shows heat transmission coefficients and other technical characteristics for the various types of windows on the European market. Technological improvements could reduce heat losses through windows to 10% of the present average level (Giovannini and Pain, 1990). Such windows would have a heat transmission coefficient comparable to that of a well-insulated wall (about 0.3 $W/m^2/°K$). Table IV.8 provides heat transmission data for building components.

Table IV.7
Window Characteristics

Glazing type	transmission coefficient k[1] (W/m²/°K)
Without selective coating	
Single	5.9
Double	2.9
Triple	2.2
With selective coating	
Single	3.0
Double	1.6-1.8
Triple[2]	1.0-1.2
Evacuated[3]	0.5

1. Glass only, without the frame.
2. With argon as insulating medium.
3. Research type.
Sources: Giovannini and Pain, 1990; Grandqvist, 1989.

Table IV.8
Heat Transmission Coefficients

	Dwelling Component				
	Window	Door	Floor	Wall	Pitched or flat roofs
Recommended values in Switzerland (1988)					
k (towards the outside) W/m²/°K	2.6	2.0	0.4	0.4	0.4
ELAK Swedish building code up to 1989 for electrically heated					
limit value (k)	2.0	1.2	0.3	0.3	0.3
target value (k)	1.5	—	0.2	0.17	0.1
Germany (1986) k value: W/m²/°K					
average stock	2.5-3.0	—	—	—	—
average new	1.6-2.0	—	0.28-0.3	0.38	—
United States (1986) k value: W/m²/°K					
average stock	—	—	1.47	0.59	0.41
new	—	—	0.58	0.47	0.22
United Kingdom (1990)					
new homes	—	—	0.45	0.45	0.25[1]-0.45[2]

1. Dwellings.
2. Other buildings.

Improving the energy efficiency of the existing building stock is important, particularly for medium-term activities, as new buildings tend to be net additions to the stock rather than replacements of existing buildings. Construction activity ranges from 1% to 3% of existing building stock, so efficiency gains in new buildings only marginally reduce future energy consumption. Refurbishing existing buildings beyond measures such as draught-proofing can mean substantial costs, which may limit such efforts. But because of country-specific circumstances, such as climate, energy prices and the efficiency level of the existing building stock, it is difficult to generalise about the attractiveness of improving existing buildings. For example, German authorities have found that refurbishing low-efficiency single-family houses up to the standards for new single-family houses (approximately equal to 14 kgoe/m^2/year) would cost about DM 45 000[1]. Danish studies indicate that the costs can be as little as the equivalent of about DM 7 500 for a single-family house to achieve 11-14 kgoe/m^2/year. This efficiency level, however, is still well above that of new low-energy houses in Denmark and Germany, which require only about 5 kgoe/m^2/year (though climatic differences need to be taken into account).

Refurbishing costs can be reduced substantially if energy efficiency measures are taken together with activities aimed at improving the level of comfort, such as replacing old windows to reduce noise. But building renovation can also lead to increased energy consumption for heating if the level of comfort is raised, for instance through higher indoor temperature or increased amount of space heated. Such trade-offs should be taken into account in the evaluation of the impact of energy efficiency improvements on energy demand levels.

Energy requirements for space heating can be reduced by installing individual metering devices and individual thermostats for dwellings or rooms. In multifamily buildings, individual metering can reduce energy requirements by up to 20%. In Germany, the Federal Government requires the installation of thermostats in all existing buildings in the new Länder by 1995 (this is an extension to the new Länder of the existing legislation).

Many of the options for increasing the shell efficiency of new buildings are most effective when applied to single-family homes, as in the case of low-energy houses with passive solar energy. However, about half the people in IEA Member countries live in multifamily buildings in urban areas with relatively old building stock. Structural characteristics exclude major portions of the building stock from the most energy-efficient measures. Thus the impact of improved shell efficiency is likely to be gradual, even though the technical potential is extraordinarily high.

The economic justification of building codes crucially depends on climate. Places with harsher climates, such as Hokkaido in Japan, generally have more stringent building guidelines because of the importance of energy requirements for heating (Koga *et al.*, 1990). In countries with milder climates, improved shell efficiency has a lower impact on energy demand and on reductions in individual energy bills.

Space heating systems. In the IEA, about 43% of space heating and cooling requirements are met by natural gas, 31% by oil and about 11% by electricity, though there are considerable regional differences. The conversion efficiency of heating systems depends on

1. On average in 1990, DM1 = $0.619.

the fuel used, on the characteristics of the burners and distribution system and on whether the system provides central or individual heating. Technological options to increase efficiency include improved boiler and furnace design, reductions in distribution losses, improved control (including ventilation) and heat recovery. For hydrocarbons and solid fuels, boiler efficiency can be improved, whereas systems based on electricity are already almost 100% efficient.

Carbon-based heating systems. Central heating systems constitute the major share of residential heating. Table IV.9 provides data for several Member countries on the overall annual efficiency of central heating systems fuelled by gas and oil (including stand still and distribution losses) and shows differences in efficiency for the average system sold and the best technology available. If the best technology available were applied, the efficiency of oil-fuelled systems could be improved by about 20% and that of gas systems, which are already more efficient than oil-based heating installations, by 10-15%. Technological developments such as improvements in the design of burners and distribution systems have contributed to increasing the efficiency of these heating systems. In Austria between 1980 and 1988, the efficiency of gas-fuelled central systems increased from 65% to 70% and that of fossil-fuelled from 60% to 68%. It is assumed that for gas units the efficiency of the stock can be improved to 80% by 2005 and to 85% by 2020. State-of-the-art technology, such as condensation furnaces, can reach efficiency of about 95%, which is close to the efficiency of electric heating systems. Including distribution losses, the overall system efficiency would be approximately 90%.

Table IV.9

Annual Overall Efficiency of Heating Systems[1] (1988)

(central units — input/output ratio in per cent)

	Oil			Natural Gas		
	Stock	Average new	Best	Stock	Average new	Best
Austria	68	72	82	70	75	85
Canada	69	69	90	71	78	96
Norway	65	80	80	n.a.	n.a.	n.a.
Ireland	65	70	75	75	80	90
Italy	60	n.a.	n.a.	60	n.a.	n.a.
Japan	n.a.	n.a.	n.a.	73	75	75
United Kingdom	65	70	75	65	70	85
United States	n.a.	n.a.	n.a.	65	78	n.a.

1. Including distribution losses.

Source: Country submissions.

The efficiency of individual units is usually lower than that of central heating units. In Austria, for instance, the efficiency of the existing stock of individual gas units is about 50% and that of the best available unit is about 60% — still lower than for central units. In principle, therefore, replacing individual units with central heating systems should provide opportunities for increased efficiency. In well-insulated dwellings, however, individual units can be more attractive because central heating is not necessary to maintain adequate comfort and the capital cost saving more than offsets the increased insulation cost. In addition, switching to a central system usually leads to changes in consumer behaviour that actually increase energy demand for space heating. Studies indicate that the energy consumption can increase up to 60% for a given dwelling, especially if the consumer has switched to a heating system with relatively low running costs, such as district heating.

Cost estimates for new systems show that the best available technology which increases efficiency 5-10%, increases price 20-50%. Instead of fully replacing existing systems, periodic maintenance can be a low-cost option. Installation firms often provide maintenance through periodic inspections. Regular maintenance can extend the lifetime of the system, increase its efficiency about 10% and contribute to its safe functioning.

Electric heating. The conversion efficiency of electric heating equipment depends on the technology and its characteristics. With resistance heating, the primary technology used, the direct conversion of electricity to heat reaches almost 100%. The overall efficiency of electric heating systems is reduced if the full fuel cycle is taken into account. The efficiency is high if the electricity is generated in hydroelectric plants. In most IEA Member countries, however, electricity is largely produced in conventional thermal or nuclear plants whose efficiency is less than 40%, and the overall system efficiency may be as low as 30%. If the full fuel cycle is assessed, the best available gas- or oil-fired heating systems can achieve higher overall conversion efficiency than electricity.

As with all space heating systems, reductions in energy use from electric heating are possible through behavioural changes and better control, such as lowering room temperature and reducing central heating distribution losses. The scope for additional improvements, both in technical and economic terms, is limited. The results of a recent IEA study analysing the scope for efficiency improvements are shown in Table IV.10. The only way to improve the energy efficiency of electric heating systems significantly would be to shift to heat pumps. By using the ambient heat they can deliver one and a half to three times as much heat per kWh as resistance heaters, but their high costs and limited performance range have limited their penetration in the residential heat market and it is likely that their impact on the overall energy demand of the residential sector will remain minimal. Heat pumps are most effective in favourable climatic conditions, such as long but not too cold winters, and where an appropriate heat source is available.

Air conditioning. The market penetration of air conditioning systems in the residential sector varies markedly by country. In countries with greater climatic extremes and higher personal income, air conditioning systems are common. In the United States in 1988, about 57% of households had air conditioning systems: 30% central units and about 27% room units. In Australia the ownership level is 35%. In Japan about 63% of homes have air conditioning and the ownership level is increasing fast. In other countries, the market penetration of air conditioning systems is insignificant. In the United Kingdom, for example, less than 1% of homes are equipped with central units. In Austria about 2% use room units; and in Italy less than 1%. However, it can be expected that market penetration in countries with the hottest summers will increase along with disposable income.

Table IV.10
Electric Heating Efficiency — Trends and Opportunities

	Electricity use per household for principal heating (MWh/year)
Western Germany	
Average stock	
1978	10.1
1986	9.1
Average new	
1978	n.a.
1986	8.2
Sweden	
Average stock	
1973	10.59
1986	9.71
Average new	
1977	7.0
1984	5.5
United Kingdom	
Average stock	
1972	6.0
1986	5.3
United States	
Average stock	
1973	7.5
1986	5.8

Source: IEA, 1989.

Data on historical efficiency developments point to considerable efficiency improvements. In Japan, the efficiency of air conditioning systems increased about 30% between 1980 and 1988 and in Canada, the equipment in place in 1988 was about 10% more efficient than at the beginning of the 1980s. Further improvements are likely, for instance in the United States, where it is expected that the efficiency of room units will increase about 50% by 2020.

Opportunities to improve efficiency include better design of the various components of the system, such as heat exchangers and fans, and better control. Table IV.11 shows the efficiency of existing equipment and the technology on the market for countries where data exist. As in the case of heating systems, different intensity of use — room units are often used only for selected rooms and not for the whole living area — can make up for what in some cases are the higher performance levels of central units.

Table IV.11

Efficiency of Residential Air Conditioning Systems (1988)

(coefficient of performance — COP)

		Existing Stock	Typical New	Best Available
Canada	central	2.1	2.2	4.4
Canada	room	1.8	1.9	3.5
Austria	room	2.2	2.4	2.5
Japan	room	3.3	3.7	3.7
United States	central	n.a.	2.8	4.7
United States	room	2.1	2.6	3.2

Source: Country submissions.

(ii) water heating

As shown in Table III.4, gas is the main energy source for water heating, providing 52% of total residential requirements. Electricity accounts for about 22% and oil about 19%. Country-specific characteristics, such as price levels, climate and personal income, mean the structure of fuel use varies substantially within the IEA. For example, electricity provides about 95% of energy requirements in Norway, and more than 50% in Italy. In the United States, about half of water heating is supplied by gas.

In some cases, the supply of hot water comes from the central heating system, which means additional appliances may be needed during the summer when no space heating is required. Such back-up systems are usually electric resistance heaters. These technologies have high conversion efficiency, close to 100% if tanks and distribution systems are properly insulated. In the United States, electric water heating systems use large central tanks, which usually cover all domestic hot water needs, including dishwashers and washing machines. Though this is still relatively uncommon in Europe and the Pacific region, its market penetration has increased in recent years. This may eventually reduce efficiency improvements if instantaneous water heating units are replaced by larger tanks, as central hot water tanks are less efficient than instantaneous electric heaters because of stand-by and distribution losses.

The efficiency of water heating units can be increased by reducing these losses — by better insulation of tanks and distribution pipes, better control or more accurate adaptation of the capacity of the equipment to the actual load requirements. It can also be increased by more efficient use of hot water — introducing low-energy shower heads, for example, or reducing the amount of hot water and the temperature requirements of appliances supplied by central tanks, such as washing machines.

Table IV.12 shows the efficiency of water heating appliances for selected countries and different fuels. The efficiency of the typical new system is about 5% higher than that of the existing stock and a further 10% could be achieved if the best available technology were applied. The energy cost, however, would not make it economic to purchase the most efficient technology, the cost of which could exceed the basic investment for a typical new unit by 40-100%. But in cases where central heating units that also supply domestic hot water are replaced, efficiency improvements can be achieved at relatively low costs.

Table IV.12
Efficiency and Market Structure of Water Heating Appliances (1988)

	Power Source	Share (%)	Existing Stock	Average New	Best Available
			(fuel output to input ratio in per cent)		
Canada	Gas	41	n.a.	53	63
Canada	Electricity	52	81	88	95
Ireland	Gas	2	65	70	90
Japan	Gas	26	79	83	83
United Kingdom	Gas	75	80	89	n.a.
United States	Gas	49	40	54.4	72
United States	Electricity	32	4 000	3 500	2 000 (kWh/year)
United States	Oil	5	52	n.a.	n.a.

Source: Country submissions.

(iii) *lighting*

Lighting accounts for approximately 11% of residential electricity consumption and about 3% of total residential energy use. The basic technologies are incandescent bulbs and compact fluorescent light bulbs (CFLs), which are substantially more efficient. Lighting efficiency can primarily be improved by replacing incandescent bulbs with fluorescent and compact fluorescent bulbs. Further options to reduce electricity requirements include improved design and better control (such as varying the light level according to function), more efficient reflectors and ballasts for fluorescent tubes or behavioural changes such as turning off lights when they are not needed. Table IV.13 provides market characteristics for lighting in several countries.

The largest reductions in energy demand can be achieved through replacement of incandescent bulbs with CFLs. Incandescent bulbs are the most widely used technology. Light is provided by low efficiency bulbs in about 95% of cases in Norway and 98% in the United Kingdom, and similar figures are found in other OECD countries (IEA, 1989). The CFL replacement for a 100-W incandescent bulb consumes about 20-25 W and the replacement for a 60-W bulb consumes 13-16 W, representing a theoretical saving of 50-75%. CFLs have achieved little success in the residential market, though they are beginning to be used in commercial establishments. The major obstacle to accelerated market penetration of CFLs is their high initial cost. Incandescent bulbs have the advantage of rather low costs, though their lifetime (about 1 000 hours) is notably shorter than that of CFLs (about 8 000 hours). The price of CFLs can be up to 15 times higher than that of conventional incandescent bulbs.

Table IV.13
Efficiency of Lighting (lumen/Watt) and Market Structure (1988)

	Existing Stock			Average Sold			Best Available		
	Incandescent	Fluorescent	CFL	Incandescent	Fluorescent	CFL	Incandescent	Fluorescent	CFL
Austria	10	100	50-80	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Italy	11.5	50	60	12.8	77	53	n.a.	n.a.	n.a.
Norway	10	80	82	10	80	82	10	80	82
United Kingdom	9-19	35-72	35-60	12	40	50	19	70	55
United States	15	78	45	15	63	45	16.5	100	60

Source: Country submissions.

(iv) *refrigeration*

Electricity use for refrigeration accounts for about 20% of residential electricity consumption, or 6% of residential energy demand. The basic technology for refrigerators and freezers is much the same across Member countries, i.e. electrically powered compressors and fans, and chlorofluorocarbon refrigerants, all of which cool insulated containers. However, beyond these technological similarities lies a wide range of differences in types and size.

Although almost all households in Member countries own refrigeration units, there have been substantial shifts in the types of models used. Reflecting changes in consumer behaviour, the market penetration of freezers and combined units (refrigerator/freezers) has increased over the last 15 years. In Sweden, for example, the ownership level of combined units increased from 6% in 1973 to almost 25% in 1986 and the ownership level of freezers increased from 55% to 76% (IEA, 1989).

From 1973 to 1986 the unit consumption of refrigerators and freezers has declined in the IEA by 10-20% (IEA, 1989), although in some cases changes in size and service (e.g. icemaking capability and automatic defrost) have led to increased electricity demand. There have also been considerable variations in energy efficiency improvements among countries. Refrigerators in Germany use only 70% of the energy needed for their 1976 counterparts and between 1985 and 1988 the efficiency of new refrigerators increased 12% (ZVEI, 1989). In Denmark, the most efficient models use only 16% of the energy needed by 1975 appliances. In Austria, the energy consumption of refrigerators per litre decreased from 2 kWh/year to 1.7 between 1980 and 1988, and a further decrease to 1.3 kWh/year is expected by 2020. But there is still a substantial gap between that and the world's best commercially available technology, which requires only about 90 kWh/year (0.45 kWh/litre/year). A Swedish prototype that is expected to be marketed soon requires only 0.35 kWh/litre/year.

Although the efficiency of a typical new unit is generally higher than that of the current stock, market aspects, such as improved service features, can result in higher electricity demand. In Ireland, for example, the efficiency of the typical new freezer is substantially lower than the stock efficiency. Table IV.14 shows, for selected Member countries, the efficiency and ownership levels for refrigerators, refrigerator/freezers and freezers, and provides information about the efficiency of the best available unit. The per-unit energy consumption (kWh/litre) of refrigerators and freezers varies considerably, depending on size and features — by a factor of as much as three (AFME, 1990).

The cost of the best available technology can be 20-100% above that of the average appliance sold today, though there is no strict correlation between efficiency and price. Technological improvements to increase efficiency influence the quality of the service provided, as extra insulation usually reduces the volume available or increases the size of the appliance. Given the standardised size of many residential appliances, changes in size could reduce market penetration because of additional installation costs.

(v) *cooking*

Energy requirements for cooking, which represent about 6% of residential energy demand, are concentrated in electricity and natural gas. In many countries during the 1970s and 1980s, the share of gas grew continuously. In Japan, Denmark and the United States, the share of gas is now about 50%. But in other countries, the share of gas is declining. In western Germany and the United Kingdom, about 80% and 50% of households respectively, are equipped with electric stoves. In Norway, because of favourable electricity prices and geographical limitations constraining the development of the natural gas grid, energy requirements for cooking are provided entirely by electricity. In Sweden, the share of electricity for cooking end-uses is around 85%.

Studies of energy demand for cooking show a decline in energy intensity in recent years (Schipper, 1988, and Energy Efficiency Office, 1990). These improvements can be related to a variety of developments, including structural changes in the types of technology used, such as the introduction of electric stoves and microwave ovens; behavioural changes, such as the number of meals taken at home and the size of the household; and efficiency improvements.

Table IV.14

Efficiency of Refrigerators, Freezers and Refrigerator/Freezers (1988)

			Efficiency					
			kWh/litre/year			kWh/year		
	Ownership (per cent)	Average Size (litres)	Average Stock	Typical New	Best Available	Average Stock	Typical New	Best Available
Refrigerators								
Austria	18	120	2	1.7	1.5	240	204	180
Denmark[1]	n.a.	n.a.	n.a.	n.a.	n.a.	350	n.a.	150
Germany[1]	n.a.	n.a.	n.a.	n.a.	n.a.	451	274	189
Ireland	70.8	164	2.1	2.0	1.5	344	328	246
Italy[2]	96	180	2.2	2.0	n.a.	396	360	n.a.
Norway	99	240	2.7	2.7	2.4	648	648	576
Sweden[1]	n.a.	n.a.	n.a.	n.a.	n.a.	475	350	250
United Kingdom	54	140	2.4	2.2	1.0	336	308	140
Freezers								
Austria	60	220	1.9	1.6	1.4	418	352	308
Canada	56.9	340	3.5	2.2	1.6	1 190	748	544
Denmark[1]	n.a.	n.a.	n.a.	n.a.	n.a.	500	n.a.	330
Germany[1]	n.a.	n.a.	n.a.	n.a.	n.a.	580	418	140
Ireland	15.7	300	2.0	1.7	1.2	600	510	360
Italy[2]	16	200	2.6	2.4	n.a.	520	480	n.a.
Norway	95	350	1.2	1.2	1.1	420	420	385
Sweden[1]	n.a.	n.a.	n.a.	n.a.	n.a.	835	550	400
United Kingdom	38	280	2.7	2.5	1.1	756	700	308
United States	34.7	n.a.	n.a.	n.a.	n.a.	1 180	750	430
Refrigerator/Freezers								
Austria	80	135	2.1	1.8	1.6	284	243	216
Canada	99.4	415	2.9	2.5	1.8	1 204	1 038	747
Denmark[1]	n.a.	n.a.	n.a.	n.a.	n.a.	600	n.a.	460
Germany[1]	n.a.	n.a.	n.a.	n.a.	n.a.	600	481	356
Ireland	26.4	260	2.2	2.6	1.0	572	676	260
Italy[2]	n.a.	n.a.	584	548	n.a.	584	548	n.a.
Japan	98.3	350	1.1	0.8	0.8	385	280	280
Sweden[1]	n.a.	n.a.	n.a.	n.a.	n.a.	700	600	450
United Kingdom	47	290	2.6	1.9	1.2	754	551	348
United States	99.8	500	2.6	2.2	1.5	1 300	1 100	750

1. 1986.
2. 1987.

Sources: Country submissions; IEA, 1989; Danish Energy Agency, 1990.

Table IV.15 shows the efficiency of the existing stock, the average new and the best commercial technology for cookers in countries where data are available. In the United Kingdom, cooking energy requirements per year and per household declined 17%, from 983 kWh to 812, between 1976 and 1988. "Best practice" behaviour could produce an energy saving of about 30% (Energy Efficiency Office, 1990). There is also significant potential for efficiency improvements from technological shifts. For example, microwaves use about 50% less electricity than conventional ovens. In the United Kingdom, the ownership level of microwaves has reached more than 40% of households. If they were used as the main cooking appliance and not only as a supplement, the energy savings would be substantial. Other technologies not yet commonly used, such as electromagnetic induction cookers, can noticeably reduce electricity demand. A study has found that these technologies can reduce the energy demand for certain modes of use by about 45% compared with gas or conventional electric stoves (Gelineau, 1990). Technological development can further increase the efficiency of electric ovens as well. A study for Austria indicates that prototypes are about 20% more efficient than the best available technology and that by 2000 an additional 11% of efficiency improvements can be achieved (Lesch, 1990). Other technology developments, however, have worked in the opposite direction. For example, the trend towards ceramic hobs instead of radiant spiral rings has adverse effects on energy demand, as these new stoves are less energy-efficient.

Table IV.15
Efficiency of Electric Cookers
(kWh/year/unit)

	Base Year	Existing Stock	Average New	Best Available
Austria	1988	470	412	407
Denmark	1988	550	n.a	380
Germany	1986	440	n.a.	n.a.
Sweden	1986	574	n.a.	n.a.
United Kingdom	1990	840	780	370
United States	1986	1 040	975	910

Source: *EEO, 1990; Schipper, 1988; Danish Energy Agency, 1990.*

(vi) *washing machines*

Washing machines, together with spin and tumble driers, consume less than 10% of residential electricity requirements. They usually have three electricity users: a water heater, an electric drive for rotation and a waste-water pump. The water heater is the dominant electricity user (about 90%). Technological efficiency improvements, different detergents, washing cycles and load factors have major effects on the energy consumed. Reductions in washing temperature can substantially reduce electricity consumption. Such behavioural changes are independent from technology and can be achieved in addition to hardware improvements. Cold water washing, often practised in North America and Japan, is often advocated as a way to increase efficiency. However, cold water wash cycles can incorporate a prewash element and take much longer than European washing machines. Detergent manufacturers state that the best results are achieved at medium to low temperatures (30-50°C). Reductions in water requirements reduce energy requirements for water heating and can also reduce the amount of waste water. Lower water and temperature requirements can be supported by improved detergents, though these may release more aggressive substances into the environment. The design of washing machines also provides the possibility of reducing the energy needed for drying. Higher spin speeds, for example, do not improve the efficiency of the washing machine, but they reduce energy requirements if tumble driers are used.

Table IV.16
Efficiency of Washing Machines
(kWh/kg)

	Ownership (Per cent)	Average Stock	Typical New	Best Available
Canada	77	20	15.3	8.6 (kWh/litre)
Denmark	n.a.	400	n.a.	255 (kWh/unit/year)
Germany	100	0.52	0.43	0.39
Ireland	77	0.66	0.4	0.38
Italy	84	0.5	n.a.	0.4
Japan	n.a.	n.a.	n.a.	n.a.
Norway	95	0.85	0.85	0.75
Switzerland	n.a.	0.57	n.a.	0.40
United Kingdom	88	0.65	0.5	0.40
United States	76	n.a.	n.a.	n.a.

Sources: Country submissions; IWU, 1989; Danish Energy Agency, 1991.

Different features and technology developments result in a large variation of efficiency. A survey by a major German utility found that the efficiency of available units range from 0.36 kWh/kg to 0.60 kWh/kg (RWE-Energie, 1990) according to differences in the size of washing machines, in the washing programmes, drying cycles and spin, and in other convenience features. The scope for further efficiency improvements is considerable. The best efficiency in 2000 (Giovannini and Pain, 1990) will approach 0.30 kWh/kg, for a 95°C cycle. In the United Kingdom, the best available washing machine has 50% lower per-unit energy consumption than the existing stock, and the best available technology world-wide consumes only one-third of the stock in place (70 kWh/year versus 210 kWh/year), but at a substantially higher cost. A study for the EC has found efficiency for washing machines in the EC overall of 290 kWh/year, with figures of 270 for western Germany, 360 for France and 390 for Denmark.

(b) market barriers and potential

One of the first measures likely to accelerate the market penetration of the energy-efficient technologies described above is the removal of market distortions and institutional barriers, which still hinder the efficient use of energy in the residential and commercial sector. There are many examples of such market imperfections. Some can be found in all sectors, while others are specific to residential and commercial energy use.

For instance, a building owner or developer is interested in reducing investment and the tenant who has to pay the energy bills is often not in a position to influence these decisions. Furthermore, in multifamily houses where individual heat requirements are not separately metered, the single customer is unaware of the real cost of heating and might regulate the room temperature by opening windows instead of lowering the temperature at the heating source. And billing and metering do not necessarily provide accurate information on energy use and costs, even if dwellings are individually metered. Such imperfections can break the feedback mechanism that is required for the market to function correctly.

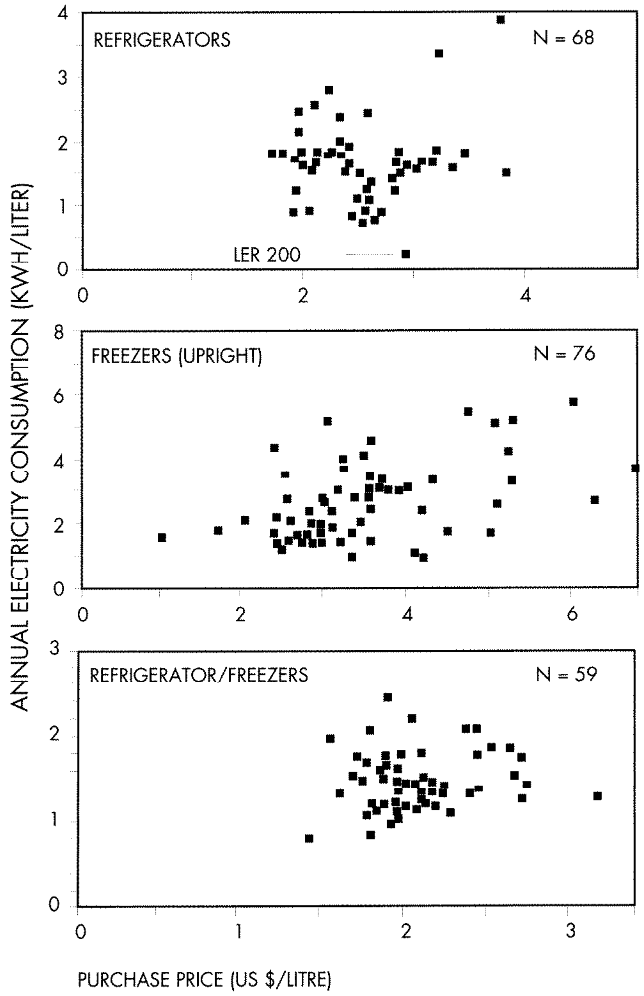
Lack of information, lack of consumer confidence in new technology, lack of capital, or simply limited interest in energy costs and in reducing energy expenses all hamper the widespread introduction of energy-efficient technology in the residential sector. Individual consumers often do not have access to information about ways of financing investments in general and energy efficiency expenditure in particular (Grubb, 1990). They make decisions to meet day-to-day requirements, of which energy-related decisions represent only a minor part, and energy efficiency is not usually the most important criterion for purchase decisions. Purchase price and the appearance of the appliance are examples of the other criteria consumers may use to select the commodity that best suits their needs. For instance, although lighting end-uses have a promising technical potential for efficiency improvements, achievements are constrained in practice by substantial market barriers. The light and brightness of energy-efficient compact fluorescent bulbs may not meet quality requirements (the consumer may even believe that these bulbs do not emit the "usual" light), lamp fixtures might have to be changed and the initial costs exceed those of conventional lighting systems.

Investments, energy costs and prices. The analysis of the cost-effectiveness of different measures to increase energy efficiency has to take account of purchase price, energy prices and the cost-effectiveness criteria used in different parts of the residential market. The large variation in equipment and energy prices across and within countries does not allow a coherent and IEA-wide assessment of the cost-effectiveness of various strategies to increase energy efficiency. The cost/benefit analysis will therefore focus on national studies and certain technologies rather than on a quantification of the energy-saving potential for the IEA as a whole.

A major problem in such an assessment is that the relationship between equipment costs and efficiency levels is not always clear. For residential appliances, for instance, available data show that there is no correlation between retail price and energy efficiency. Figure IV.1 illustrates this relation for a sample of refrigerators, freezers and refrigerator/freezers available in Sweden. For a given price level, efficiency can vary by a factor of two or three. This variation reveals that energy consumption is not very important for product development and consumer purchase behaviour. As a result, it is difficult to assess the cost-effectiveness of energy efficiency investments. It is possible to improve energy efficiency without additional costs, or to reduce the investment without increasing energy consumption. Presumably, different appliances provide different amenity levels that the consumer appreciates. Therefore, though consumers can buy efficient technology without additional cost, the amenity level may change.

Figure IV.1

Lack of Correlation between Price and Energy Consumption for Refrigerators and Freezers in Sweden

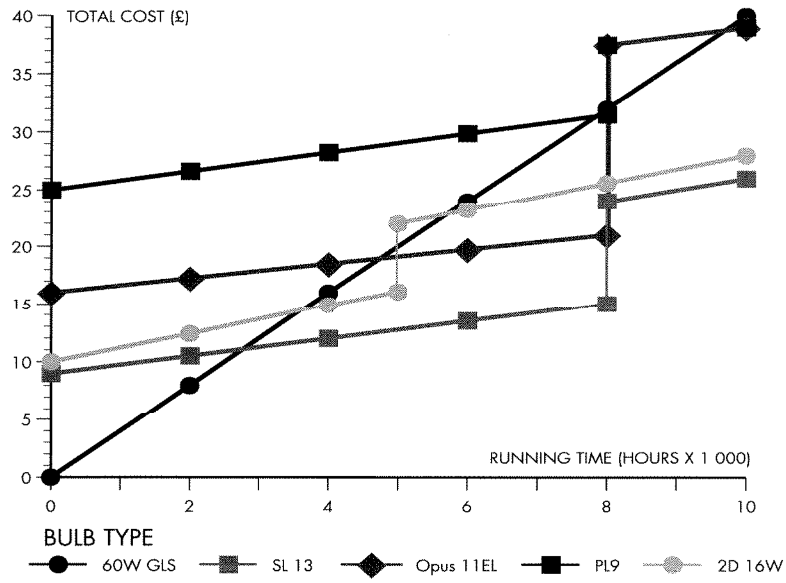


Source: Bodlund et al. 1989.

Price levels and the structure of energy prices are another important variable for the cost-effectiveness of energy efficiency investments. Brandt (1988) has analysed how this affects the payback time of investments in gas and electric appliances for different countries. Electricity and gas tariffs usually consist of an energy charge depending on actual anergy requirements (for instance, kWh) and a demand charge that is largely independent from consumption. Variations in the share of the demand (fixed) charge can noticeably influence the benefits of efficiency investments. For example, the payback period for efficient refrigerators can be reduced from more than nine years for tariffs with a high fixed share to less than six years for tariffs that largely consist only of energy charges (linear tariffs). Tariff structures vary considerably among IEA Member coutnries and, as a result, so does the cost-effectiveness of energy investments.

Figure IV.2

Comparison of Lighting Costs of Incandescent and Fluorescent Bulbs



Source: EEO, 1990.

Conditions of use is another criterion that has to be taken into account. For example, the intensity of the use of efficient light bulbs considerably influences the cost-effectiveness of the investment, as shown in Figure IV.2. Investments for CFLs range between £9[1] and £20 — 18 to 40 times higher than those for incandescent bulbs, which cost only about £0.50. This investment differential constitutes a substantial barrier to purchase. On the other hand, if CFLs are operated more than five hours a day (about 2 000 hours a year), the returns can pay back the investment in less than two years. In several Member countries there have been significant cost reductions for CFLs in recent years. In Denmark, for example, the price for CFLs fell from DKr 300[2] in 1987 to DKr 125 in 1991 (equivalent to about £11). This has

1. On average in 1990. £1 = $1.776.

2. On average in 1990, Dkr 1 = $0.162.

primarily been a result of demand-side management campaigns by electric utilities, such as give-away or rebate programmes.

Table IV.17

Costs and Benefits for Efficiency Investments in the Residential Sector

(typical single-family house)

Measures	CCE[1] ($/kWh)	Incremental Cost ($)	Lifetime (years)	Energy Savings (kWh/year)	Cumulative Savings (kWh/year)
Water heater blanket	0.009	25	10	400	400
High efficiency washing machine	0.023	50	15	240	640
Thermal traps on pipes	0.036	35	10	140	780
Average heat pump	0.055	750	15	1 500	2 280
Best heat pump available	0.059	300	15	560	2 840
Hot water pipe drain system	0.16	225	15	150	3 260
De-superheater on air conditioner	0.24	700	15	420	3 410
Shower bath economiser	0.30	300	10	140	3 550

1. Cost of Conserved Energy, i.e. the annualised investment cost (including operation and maintenance) divided by the annual energy savings.

Source: Vine, 1990.

Table IV.18

Examples of Avoided Emissions and Their Costs:
Electricity End-Use Efficiency

	Measure Resource Cost ($/kWh)	Cost of Avoided Carbon Equivalent ($/metric ton)
Available End-Use Efficiency Technologies		
- Available-Lighting (incand. - compact fluorescent)	-0.011	-171
- Available-Lighting (efficient fluorescent tube)	-0.007	-159
- Available-Lighting (lamps, ballasts, reflectors)	0.013	-96
- Refrigerator/freezer, no CFCs	0.018	-79
- Freezer, automatic defrost, no CFCs	0.022	-67
- Heat-pump water heaters	0.034	-30
- US field data, multifamily, htg. retrofits	0.038	-19
- Retrofits in 450 US commercial buildings	0.026	-54
- No-cost or behavioural measures	0	-137

Source : Mills, 1991b.

Several studies have analysed at a national level the economics of efficiency measures. Table IV.17 shows the investments and costs of saved energy for a single family house in the United States (Vine, 1990). At 1988 electricity prices ($0.075/kWh), most of the investments calculated on the basis of the cost of conserved energy would be cost-effective and result in substantial energy savings.

Another study explicitly analysed the economic efficiency of technology to reduce greenhouse gas emissions (Mills, 1991b). The results, shown in Table IV.18, are expressed in terms of the cost of avoided carbon equivalent (CO_2 and other important greenhouse gases): the cost of a strategy to reduce emissions minus the cost of a base-case strategy, divided by the amount of emissions reduced ($/metric ton). A net cost of avoided carbon equivalent corresponds to a net economic benefit, as the cost of the emission-reducing strategy is lower that of the base-case strategy. Strategies focusing on lighting efficiency generate the largest economic benefits.

The British Energy Efficiency Office (EEO) has assessed the cost-effectiveness and energy impact of improvements in the efficiency of domestic electric appliances in the United Kingdom (EEO, 1990). Table IV.19 summarises the cost-effectiveness of replacing various end-use technologies with the world's best appliances. Investments in efficient refrigerators and dishwashers would be paid back in three and 2.3 years, respectively. The total payback time for various appliances would be over four years and achievable energy savings would result in an electricity peak demand reduction of 5 GW per year. The results for a similar assessment of costs and energy savings for western Germany are shown in Table IV.20.

Conclusions. The analysis of technical opportunities for energy efficiency improvements in the residential sector has shown that for virtually all residential energy uses, there is a saving potential, ranging from 10% to 75%. Lighting and space heating have the largest potential, while that for end-uses such as clothes washing, water heating and cooking is considerably smaller. Efficiency improvements likely to occur under market conditions are assessed below, taking into account the fact that the barriers to efficiency improvements described above would have to be overcome. This IEA-wide assessment is only indicative, as the scope for efficiency improvements varies considerably because of country-specific factors. Furthermore, bottom-up approaches, particularly at an international level, tend to overestimate savings because changes in factors such as the size of appliances or in individual behaviour cannot always be included (Koga *et al.*, 1990).

Space heating is by far the largest end-use category and, from a technical point of view, offers great opportunities for demand reductions. Heat losses of the **building shell** can be substantially reduced and the efficiency of **heating systems** can be further improved, although substantial progress has already been made over the last 15 years.

In the case of new buildings, low-energy houses could reduce energy requirements for heating (and cooling) by more than 75% from the levels currently required for new buildings. Such reductions would be economic only under certain climatic and other specific conditions. For the vast majority of new buildings, improved insulation and other shell-oriented measures, such as double- or triple-glazed windows and improved ventilation, can be included cost-effectively in the building design and reduce heat requirements about 25-35%. But because of the slow stock turnover, the impact of efficiency measures for new buildings makes only a small, long-term difference in overall residential energy demand.

Table IV.19

Summary of Costs and Benefits to Move to World Best Practice, United Kingdom

Appliance Type	Refrigeration	Lighting	Washing Machine	Tumble Drier	Dishwasher	Cooking	Others	Total
Extra cost of world best appliances (£M)	1 500	1 700	1 000	620	90	1 200	—	6 100
Annual electricity savings (GWh)	8 300	6 100	2 200	1 800	600	4 700	2 100	26 000
Value of saved electricity (£M)	500	370	130	70	40	280	130	1 500
Simple payback (years) to the consumer	3	4.7	7.7	8.9	2.3	4.3	—	4.1
Peak demand reduction (MW)	1 000	1 400	500	400	100	1 100	500	5 000

Source: EEO, 1990.

Table IV.20

Investments and Energy Savings — Domestic Appliances, Germany

	Dishwasher	Washing Machine	Tumble Drier	Refrigerator	Fridge/ Freezer	Freezer
Consumption average stock (1988)	100%	100%	100%	100%	100%	100%
Consumption best available (1988)	84%	73%	92%	77%	83%	57%
Energy savings (kWh/year)	63	54	32	49	68	134
Marginal investments (DM)	0	0	28	37	0	58
CCE[1] (DPf/kWh)	0.0	0.0	5.6	7.3	0.0	4.4

1. Cost of Conserved Energy.

Source: IWU, 1989.

For existing buildings, most available technology would be economic only as part of general building renovations. The age of the building stock, the location and the type of the building can exclude certain efficiency measures for economic and practical reasons. The most promising measure to reduce heat requirements is improved wall and roof insulation, which could help reduce energy demand by about 25%. Other measures, such as replacing windows, would be substantially more costly. The impact on overall energy demand for heating is limited by the rate of renovation of the existing building stock.

Efficiency improvements for **space heating systems** depend on the type of system and the kind of fuel used. Electricity-based systems are already highly efficient at the end-use level (though the overall efficiency of electricity production and distribution may be low), while those based on oil and gas can be further improved as the existing equipment is replaced by new boilers that are approximately 15% more efficient than the existing stock. Further improvements in the whole of the heating system, in the range of an additional 5-10%, could be achieved through reductions in distribution losses and better control. Taking into account the relatively long lifetime (about 15 years or more) of space heating systems, these achievements can be reached only in the medium term. Another option would be to replace conventional systems with heat pumps. However, although substantial reductions in energy demand and operational costs can be achieved, the high initial cost of heat pumps limits their market to certain niches.

Lighting shows, in theory, the largest saving potential, through the introduction of compact fluorescent light bulbs, though under current conditions the application of CFLs is not cost-effective for large market segments in the residential sector. If their high initial costs were reduced, CFLs would be a promising option in the medium term, though it would not be cost-effective to replace all incandescent bulbs. Even for bulbs that are used for longer periods, it would be rational to invest in CFLs only if discount rates of 7-20% were applied. Such investments would yield sufficiently high rates of return only if the bulbs were used more than 1 000 hours a year (McInnes and Unterwurzacher, 1991). This concerns a limited segment of the residential lighting market, as only two or three bulbs per dwelling are used more than 1 000 hours a year.

Refrigeration also has a substantial saving potential. The efficiency of the stock has improved about 10% over the last decade. The efficiency of the existing stock indicates that per unit consumption could be reduced about 35-50% using the best commercially available technology and about 15% to 30% compared with the average new technology. But there are factors that counteract efficiency improvements. Although the best available technology could provide sufficient returns to justify higher investment costs, in many cases consumers are not prepared to pay more for energy efficiency improvements, and other criteria, such as colour or service features, may be considered more important.

In the case of other residential end-uses, such as **cooking** and **clothes washing**, the best available technology usually entails longer payback periods than for refrigeration and lighting (EEO, 1990), and numerous non-technical factors make it extremely difficult to predict the demand impact of such energy-efficient technology. Behavioural differences in cooking, the use of microwave instead of conventional ovens, the variety of different technologies with substantially different energy requirements, and differences in lifestyle are difficult to assess, though they probably play an important part in determining energy demand developments.

The end-use with the lowest saving potential is probably **water heating**, despite the fact that water heating absorbs a considerable share of residential energy use. The characteristics of this market segment make it likely that the scope for cost-effective energy savings is limited, particularly if measures focus only on improvements of water heating systems. In many cases, however, water heating is part of the central heating system and economically justifiable efficiency improvements can be carried out if the central heating system is replaced. In the case of stand-alone systems, electricity and gas are the main energy source. Electricity-based units generally operate at high efficiency levels and provide only limited scope for further improvements — perhaps about 5% — through better insulation and control. The use of gas and condensing boilers offers considerable opportunities for energy savings.

2.3 Potential in the commercial and public sector

(a) technical potential

Energy requirements in the commercial sector are dominated by three end-use categories: space conditioning, lighting and office automation. As shown in Table III.5, space conditioning uses about 60% and lighting about 17% of the energy demand of the commercial sector in IEA Member countries. Electricity demand for office automation can be significant for certain activities, and in some premises office automation consumes almost the same amount of electricity as lighting does (Norford *et al.*, 1989).

There has been no extensive research on energy demand developments and the energy efficiency potential of the commercial sector, because the commercial sector accounts for only a small part of TFC (about 11% in 1988) and in many service-sector activities, energy requirements and related costs are less important than for industry. Energy in the commercial sector has a primarily supporting function and office managers do not consider reducing energy costs as a priority, even if energy efficiency investments meet the requirements for capital return usually applied in business.

There are nevertheless factors that are increasing interest in energy efficiency in this end-use sector. Energy end-use is less dispersed than in the residential sector, being concentrated in the three major categories mentioned above. A large part of energy use is related to space conditioning and can be reduced by increasing the efficiency of the building shell and improving the heating and air conditioning system. Furthermore, commercial electricity use has been growing rapidly and in many Member countries there is concern about meeting further increases in electricity demand. Electricity efficiency measures in the commercial sector can contribute to solving this problem. For example, conservation programmes that concentrate on lighting in commercial buildings can be very cost-effective and achieve considerable reductions in electricity demand (Marbek, 1986).

But any assessment of the energy efficiency potential of the commercial sector is complicated by significant data problems, because commercial activities are extremely varied and have very different demand structures. The service sector includes office buildings, trade, health care, education and other services, such as restaurants and hotels. Table IV.21 illustrates the relative importance of these different commercial activities, for countries where data exist.

Table IV.21

Structure of Commercial Buildings

(buildings and energy)

	United Kingdom		Sweden		Norway		Ireland		Canada		Japan		United States	
	1985		1988		1988		1988		1988		1988		1988	
	'000		'000		'000		'000		'000		'000		million	
	buildings	ktoe	buildings	ktoe	buildings	ktoe	buildings	ktoe	buildings	ktoe	m^2	ktoe	m^2	ktoe
Large Office														
(>1 000 m^2)	84	1 380	7.9	358	14.9	n.a.	0.30	130	126.6	8 497	39 006	n.a.	946	n.a.
Small Office	212	n.a.	5.6	35	30.0	n.a.	n.a.	n.a.	31.6	n.a.	n.a.	n.a.	n.a.	n.a.
Trade	864	4 427	8.3	281	9.9	n.a.	20.00	190	165.1	6 330	28 123	n.a.	1 245	n.a.
Hotel/rest.	43	809	4.1	157	3.3	n.a.	0.68	50	28.8	2 880	7 542	n.a.	193	n.a.
Education	93	6 307	7.2	566	23.7	n.a.	3.30	260	76.5	1 595	30 280	n.a.	684	n.a.
Health	19	2475	2.0	408	6.6	n.a.	0.30	n.a.	48.9	500	7 332	n.a.	477	n.a.
Other	290	n.a.	14.4	n.a.	179.7	n.a.	—	730	47.6	309	8 935	n.a.	863	n.a.

Source: Country submissions.

As a result of changes in the economic activity of IEA Member countries, the number of buildings and energy used by certain service activities have substantially expanded. For example, in the United Kingdom between 1980 and 1985, energy consumption increased 26% for offices and 23% for trade. In contrast, energy demand for hotel services and education/public services fell and that for health care was unchanged. In Norway, the number of office buildings increased by 18% between 1980 and 1988. These structural shifts have considerable effects on energy demand, particularly on electricity demand. Increased office space usually requires more energy for lighting, space conditioning and office equipment. Growth in buildings used for hotel and restaurant services or health care increases energy demand for heating.

Future energy demand developments, in terms of both fuel mix and volumes, depend on the level of building activity for commercial purposes and on structural shifts. Structural data concerning future developments of the building stock are available for only a few countries. For example, in Norway the building stock is forecast to increase 43% between 1988 and 2005. In Japan, it is assumed that the floor space (m^2) for trade-related activities will increase 55% between 1988 and 2005, and that for hotel services will rise 60%, while space requirements for education/public services will remain nearly unchanged. Forecasts for the United States indicate that office space requirements will increase 60% by 2005, from 1988 levels, and a further 43% by 2020. Space requirements in 2005 are expected to have risen 43% for trade, 11% for education and 49% for health care.

Table IV.22 shows energy intensities for large offices, health care facilities and hotels, both for existing and for new buildings, in IEA countries where data are available. Energy requirements for space conditioning and lighting account together for about 80% of the commercial sector's energy use. But of course there are country-specific differences according to the importance of certain commercial activities and to the local climate and economic parameters. In Ireland, for example, about 200 kWh/m^2 are used for space conditioning and about 46 kWh/m^2 for lighting in new buildings. The most efficient buildings require only about 100 kWh/m^2 for space conditioning and 30 kWh/m^2 for lighting.

(i) heating and cooling

The major energy sources for space conditioning in the commercial sector are gas and oil, which account for about 70% of 1988 commercial energy demand. In large commercial and public buildings, nearly all space heating is provided by steam or hot-water boilers. In small commercial buildings, room heaters are commonly used. Electricity is usually used for cooling, particularly in Europe and in the Pacific region, and accounts for about 26% of the commercial sector's energy demand for space conditioning. In the United States, natural gas covers about 20% of energy demand for cooling, though this share decreased considerably between 1980 and 1988.

Building shell and envelope. The technical potential for energy efficiency improvements from measures on the building shell is similar to that of residential buildings, though zero-energy design cannot be used for commercial premises. The function of a commercial building largely defines its location and energy requirements for ventilation and cooling.

These factors mandate certain designs that are incompatible with the constraints of high-efficiency construction. Table IV.23 provides figures for thermal efficiency requirements for existing and new commercial buildings in selected IEA countries. For countries in milder climates, such as Turkey, these prescriptions are substantially less stringent, as energy requirements for heating are lower and tough codes would not be economic. On the other hand, energy requirements for cooling may be higher.

Table IV.22

Energy Intensity of Commercial Premises (1988)

(kWh/m²/year)

	Large Offices		Trade		Health Care		Hotels	
	existing	new	existing	new	existing	new	existing	new
Canada	492	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Japan[1]	62	n.a.	75	n.a.	267	n.a.	112	n.a.
Ireland	500	300	500	300	600	300	600	300
Italy[2]	523	n.a.	523	n.a.	523	n.a.	523	n.a.
Norway	220	190	250	230	300	220	275	230
Sweden[3]	279	n.a.	313	n.a.	286	n.a.	342	n.a.
United Kingdom[4]	253	n.a.	200	n.a.	655	n.a.	422	n.a.
United States	297	n.a.	234	n.a.	378	n.a.	378	n.a.

1. Heating and cooling demand.
2. Valid for all premises.
3. Heat and hot water.
4. 1985.
Source: Country submissions.

Table IV.23

Thermal Efficiency of Existing and New Commercial Premises

(W/m²/K)

	Ireland		United Kingdom		Norway[1]				Turkey
					1988		2005		
	existing[1]	new	existing[1]	new	existing	new	existing	new	existing
Wall	1.5	0.6	0.6	0.45	0.6	0.30	0.45	0.25	0.87-1.74
Roof	1.1	0.4	0.6	0.25	0.57	0.20	0.40	0.17	0.38-0.96
Floor	0.5	0.4	n.a	0.45	0.59	0.20	0.45	0.17	0.64-1.78
Window	5.6	4.2	n.a	n.a.	3.07	2.40	2.90	2.00	5.2

1. Large offices.
Source: Country submissions.

The cost-effectiveness of improvements in existing buildings also depends on the building type. Hospitals and other buildings that are heated all day at relatively high temperatures offer the best return. Offices, schools and warehouses are usually less attractive investments, unless they are being renovated or existing insulation levels are very low, as can be the case for buildings constructed in Europe between 1945 and 1975.

Space conditioning appliances. The efficiency of the heating and cooling system can be increased by improving boiler systems and room heaters, control systems, air conditioning and heat recovery. The potential savings described below cannot be totalled because they are interrelated. For instance, sophisticated heating systems that can reduce energy consumption 30-40% are usually equipped with state-of-the-art control devices.

Improved boiler systems, including the distribution systems, have the largest potential for energy efficiency improvements. In the United Kingdom, replacing existing systems with conventional boilers would reduce energy consumption 15-20% and the use of condensing boilers would result in a 30-40% energy saving (EEO, 1988). Room heaters, such as electric and gas radiant and convector heaters, can be very effective in smaller buildings with intermittent use, such as shops and offices, though they do not provide the same level of comfort as central heating systems. The potential for energy savings is limited by the fact that most of these premises would have their systems upgraded to central heating in the event of renovation. As in the case of residential buildings, this can result in higher energy demand.

Control devices range from simple switches that lower the indoor temperature overnight, to sophisticated devices using microprocessors that control maximum load, heating, cooling and lighting, and monitor occupancy. The potential for energy savings through the use of control systems is high. With lighting control systems potential savings range from 30% to 70%. Overall, total potential savings of perhaps 10-20% of current building energy demand are possible (EEO, 1988).

Energy requirements for air conditioning depend on the building design and the equipment and control mechanisms used. Air conditioning use in existing buildings can be cut by reducing heat gains, increasing efficiency and reducing distribution losses. Heat gain in air-conditioned rooms can be reduced by insulation, solar shading and reduction of the ventilation rate. In new buildings, careful design provides many opportunities for reducing or even eliminating air conditioning load requirements. Design balancing the need for cooling and heating can also make the application of heat pumps economically attractive. Air conditioning systems are responsible only for a small share of the commercial and public sector's energy demand, though this share is growing fast in many countries. In the United Kingdom, for instance, the number of air-conditioned offices doubled over a five-year period in the 1980s.

(ii) lighting

In commercial and public buildings, fluorescent lighting systems dominate the lighting market, with market shares ranging from 59% in Italy to about 90% in Norway, as shown in Table IV.24. The rest of the market is covered by incandescent and high-intensity systems. Electricity use for lighting accounts for approximately 40% of the IEA's electricity requirements in the commercial and public sector.

From a technical point of view, substantial improvements can be made either by replacing incandescent systems with fluorescent bulbs or by using electronic ballasts rather than conventional and high-efficiency bulbs. Major savings can also be obtained by better lighting system design and control, more efficient reflectors, the varying of the light levels according to function, the use of natural light through better building design and controls that turn off lights when they are not needed. Improved efficiency or reduced artificial lighting also reduces the amount of heat released in air-conditioned buildings. During the heating period, however, efficient lighting slightly increases requirements for space heating.

Table IV.24

Estimates of Electricity End-Use for Lighting in Commercial Sector

	Total Electricity Demand (TWh)	Incandescent	of which (%) Fluorescent	High Intensity
Canada	n.a.	29	71	0
Ireland (1988)	n.a.	5	90	3
Italy (1986)	n.a.	25	50	25
Norway (1988)	3.57	8	89	1
Sweden (1985)	6.30	18	79	3
United Kingdom	23.10	45	55	0
United States (1988)	220	14	75	5

Sources: IEA, 1989; Country submissions.

Higher electricity use in commercial buildings compared with residential buildings has resulted in an increase in the use of efficient lighting systems. However, lighting represents a small share of total business costs and existing lighting systems are likely to be replaced only when major building modifications are undertaken. These factors limit the penetration of high-efficiency fluorescent lighting, even though characteristics of the use of lighting in commercial premises may make such investments more attractive than in the residential sector. Studies indicate that for office buildings — which constitute the largest market segment for fluorescent lighting systems, along with hotels and shops — investment in high-efficiency systems could be paid back in less than six months (Marbek, 1986).

(iii) office equipment

Office equipment, such as personal computers (PCs), fax machines and copiers, is an area that is growing in size and variety. Although there have been rapid technological developments and efficiency improvements, the rate of market penetration of such devices has by far outweighed energy savings. Further efficiency improvements are likely, however, driven by requirements for improved service rather than by energy-cost considerations. For example, laptop computers require the development of microprocessors that consume less electricity than desktop units. Such chips will probably be applied later to desktop computers and therefore influence the energy efficiency of the whole PC market.

(b) market barriers and potential

Some of the market barriers in the commercial and public sectors are similar to those in industry and the residential sector. As in industry, energy holds a primarily supporting function and activities that reduce energy costs are not usually a priority. And as in the residential sector, when a building is leased or rented, the responsibilities over investments and energy costs are split between owner and occupant. Other market barriers, which can be particularly serious for small enterprises, include lack of access to capital and lack of information on the availability of technologies and how they affect energy costs. Managers are often not aware of the actual energy costs or options to reduce them, even simple and cheap measures such as better control. In the public sector, energy-related expenditures are often the responsibility of central authorities or procurement offices and the occupant has to be encouraged to behave in an energy-conscious way. In addition, there is generally no control over the actual energy cost of single buildings.

Energy requirements for **space heating** in the commercial sector offer considerable potential for improvements through better design of new buildings as well as through improved heating systems, better control and more efficient air conditioning. The last three measures can also be applied to existing buildings. Available data show that for new buildings noticeable efficiency gains can be expected because of the insulation levels required by building codes. For existing buildings, major energy savings can be realised through the renovation of the building shell and improved control systems. However, the overall energy impact of such improvements, which can be as much as 30-70%, depends on the type of building, existing insulation levels, the climate and energy price levels.

Improvements can be achieved in **commercial lighting** through further market penetration of fluorescent bulbs and replacement of existing fluorescent fixtures with high-efficiency systems, ballast and control devices, which can be cost-effective.

Table IV.25 shows the cost-effective saving potential for existing commercial and public buildings in the United Kingdom (EEO, 1988). In this study, an investment is considered cost-effective if it is paid back in less than three years, which corresponds to a rate of return of about 25%. Savings from space heating and lighting account for 75% and 13%, respectively, of total savings, together amounting to close to 90% of the total. Investments for draught-proofing, replacement of incandescent with fluorescent bulbs, loft insulation and optimisation of hot water use to reduce storage and circulation losses could be paid back within three years. Conversion of boiler plants from oil to gas, cavity wall insulations, changes of pipes to improve the efficiency of heating systems and reducing glazing by adding insulating panels would result in a payback time of three to six years. Investments in double glazing or waste heat recovery installations would produce energy savings that balance the initial costs in more than six years. However, as described above, various barriers preclude this potential's being fully exploited. In addition, as these calculations are based on 1984 fuel prices, current energy prices may mean longer payback periods.

Table IV.25
Estimates on Cost-Effective Potential for Savings in Non-Domestic Buildings in the United Kingdom

More efficient methods of heating	15%
Insulation and related measures	5%
Reduced ventilation	2.5%
More efficient water heating	0.5%
Lighting	4%
Electrical and miscellaneous equipment	2%

Source: EEO, 1988.

2.4 Potential in the road transport sector

(a) technical potential

In line with the basic time frame chosen for the study, the analysis of the potential for technological fuel efficiency improvements concentrates on the period to 2005. In terms of technology that is likely to penetrate the market by this date, given the lag time necessary for changes to be fully integrated in vehicle manufacturing chains, this means taking a relatively short-term perspective. Technology that is relatively well developed is likely to be introduced by the mid-nineties. Technology in earlier stages of development is unlikely to be brought into production until the second half of this decade. Some of these will probably not reach commercialisation until the beginning of the century.

In order to evaluate the potential for technological fuel efficiency improvements, it is first necessary to understand where energy losses occur in today's vehicles. The energy losses in a representative vehicle travelling over a mix of urban, rural and motorway routes are described in Table IV.26. Only about 18% of the energy content of the vehicle fuel is available as shaft power for the wheels. Over 80% is unproductive energy, spent in overcoming internal friction in auxiliary items and in thermodynamic losses in the engine, which are manifested as heat rejected to the coolant and the exhaust. The scope for reducing engine thermodynamic losses is limited by the theoretical efficiencies of the operating cycles used in heat engines. In addition, what power does reach the wheels must be used to overcome the aerodynamic drag of the vehicle (especially at high speeds) and its rolling resistance. If there were no internal energy use or losses, a passenger car could have fuel consumption of about 1.3 litres/100 km (Von Hippel, 1987).

Table IV.26
Energy Losses in a Typical Car
(%)

Thermodynamic and Mechanical Losses	
Transmission	2
Auxiliaries	8
Radiation	12
Exhaust	20
Coolant	40
Losses in Overcoming Forces Associated with Motion	
Aerodynamic Drag	4
Rolling Resistance	6
Braking	8
Total	100

Source: OECD, 1982.

The technical characteristics and design of a vehicle depend upon many interlinking and conflicting objectives, including performance, comfort, safety, emissions, fuel economy and vehicle costs. The relative importance of these factors is determined by the manufacturer, competitors and the market, as well as by regulations. In terms of fuel economy, relevant technical items in addition to engine type are vehicle weight, aerodynamics, tyres, steering and suspension, and transmissions.

Vehicle weight. The major weight components in a car are the body (28%), engine and transmission (21%) and trim plus glass (16%). The weight of the engine and body could be reduced substantially by the use of light alloy materials, plastics and ceramics and by improving the design of individual components. A 10% reduction in weight results in a decrease in fuel consumption of about 2.5% at 140 km/h and about 6% in city driving conditions (Businaro and Fedrighini, 1981). Thus a 3-5% fuel consumption reduction is likely to result from each 10% reduction in weight, though the weight reduction would have to be accompanied by optimisation of engine performance and gear ratios for maximum advantage.

The use of plastics and aluminium is likely to continue to increase, though not as much as was thought a few years ago. The use of magnesium, which is one-third the weight of steel and two-thirds that of aluminium, is essentially determined by the price of aluminium. The major change to ceramics predicted a few years ago now seems unlikely, as test results have not confirmed the anticipated economy improvements. Future applications are likely to be relatively discrete. The use of composites depends upon the results of experience currently being gained, particularly with respect to fatigue characteristics. All together, though the proportion of steel and cast iron in the vehicle is likely to decrease from around 60% in 1986 to 50% in 2000 (Martin and Shock, 1989), the weight of ancillary equipment, such as electrical devices and additional safety and noise control equipment, could increase. The net effect is likely to be a smaller overall weight reduction than would be achieved by displacement of steel alone.

Aerodynamics. A 10% reduction in the drag coefficient results in a reduction in fuel consumption that ranges from about 2.5% for city driving to 7% at 140 km/h (Businaro and Fedrighini, 1981), meaning an average 3-4% saving in fuel consumption for a typical European vehicle. If the drag coefficient were halved, the power required at a given cruising speed would be reduced by about 36%, allowing the use of smaller engines (EIU, 1989). Much of the fuel economy improvement achieved in the last 15 years is due to better aerodynamics. In 1973, baseline drag was about 0.45; now 0.3 is relatively standard in European cars. However, drag coefficient alone is not a measure of the drag force exerted on the moving vehicle. Vehicle speed, frontal area and tyres also have to be taken into account. In the United Kingdom, the average drag coefficient of the current vehicle population is 0.36. An analysis of the scope for drag reduction has shown that a decrease of approximately 45% is feasible, giving a practical car design with a drag coefficient of about 0.2, as shown in Table IV.27. Significant savings can also be achieved by improving the aerodynamics of trucks, for which a reduction of drag from 0.711 to 0.325 produces overall fuel savings of 25%.

Table IV.27

Component Drag Coefficients and Potential for Reduction

Drag Coefficient Component	Typical Current Value	Minimum Feasible Value
Forebody	0.055	0.015
Afterbody	0.14	0.07
Underbody	0.06	0.02
Skin Friction	0.025	0.025
Total Body Drag	0.28	0.10
Wheels and Wheel Wells	0.09	0.07
Drip-Rails	0.01	0
Window Recesses	0.01	0.005
External Mirror	0.01	0.005
Total Protuberance Drag	0.12	0.08
Cooling System	0.035	0.015
Total Overall Drag	0.435	0.195

Source: Energy Efficiency Office, 1989.

Tyres, steering and suspension. For lower rolling resistance, tyres need to be narrow and inflated to high pressure, but this tends to make them noisier. A rolling resistance reduction of 40% and a weight saving of 30% can reduce consumption at 90 km/h by 7% (OECD, 1986). During the 1980s, tyres tended to become wider, but advances in car technology, such as four-wheel drive and steering and active suspension systems, should make it possible to reduce their width. Active suspension systems in particular will provide the greatest influence on tyre design, as improved control of the tyre/road contact reduces the necessity of squat section tyres to provide the desired grip.

Transmission. The prospects for improved fuel efficiency by modifying existing gearboxes are relatively modest, around 5% of overall fuel consumption at best. But a vast number of new transmissions are being developed throughout the world. Engines operate most efficiently only within small ranges of combined speeds and powers, and maximum efficiency is attained when the engine runs slowly under high loads. Part-load performance can be improved by selecting appropriate gearing to increase the load for the performance required. The most worthwhile developments would be transmissions with continuously variable gear ratios and automated transmissions that enable the engine to be matched more closely to the vehicle load. These systems are estimated to provide up to a 20% improvement in fuel consumption compared with a four-speed gearbox when fitted to a conventional gasoline-fuelled car.

Electronics and engine management systems. Designs of engine management systems have reached a high level of complexity but full implementation of this type of equipment is dependent on the development of reliable communications networks and improved sensors. The motor industry generally views this technology as essential for meeting emission standards while maintaining driving comfort and low fuel consumption. A further attraction is that microprocessor-based systems can be used for sophisticated control functions in the vehicle and this has customer appeal, particularly in the high-performance and luxury parts of the market. In the United States, both Ford and General Motors used microprocessor systems on all their 1988 models.

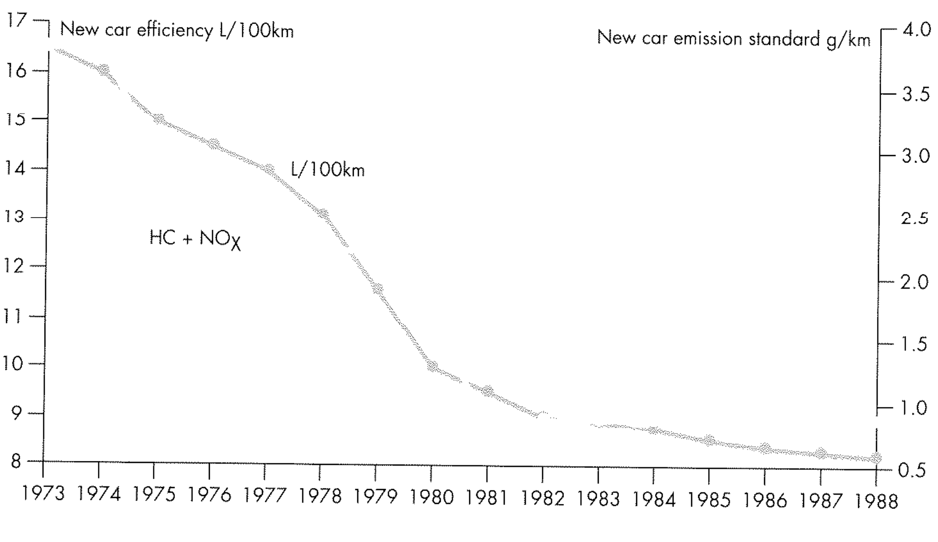
Engine type. Two engine types are currently available: the spark ignition engine fuelled by gasoline and the compression ignition engine fuelled by diesel. The spark ignition engine is cheaper and offers good performance in terms of acceleration but at the expense of fuel economy. Compression ignition engines offer better fuel consumption, particularly at part load, but at a higher capital cost and with more noise, vibration, bulk and weight. Tests have shown that diesel cars have a considerably lower fuel consumption by volume than gasoline cars (about 20-30% less), but as the energy content per unit volume of diesel fuel is greater than that of petrol, the primary energy consumption advantage of diesel is only 15%. Historically, passenger cars and other light vehicles have used gasoline engines because of their high performance characteristics and diesel engines were used for heavier vehicles such as buses and trucks. After the first oil crisis, the diesel engine was adapted to lighter-duty use in order to take advantage of its superior fuel economy. The penetration of diesel into the lighter vehicle category was most marked in some European countries such as Italy and Germany, while it was more limited in North America.

Both types of engine offer scope for further development. For spark ignition engines attention is focused on fuel/air mixture preparation, combustion chamber design and higher compression ratios, while for compression ignition engines improvements to in-cylinder processes and turbocharging could prove beneficial. The most fuel-efficient direct injection diesel engines are only just being introduced for passenger cars. The best modern diesel engines can give excellent fuel economy by current standards, and it is significant that many of the high-efficiency prototypes under development (see Table IV.29) are based on diesel technology. However, the prime area of engine development work remains the design and production of engines and vehicle systems that can comply with new, more stringent environmental regulations. It is therefore important to consider the impact these regulations will have on engine designs and on fuel consumption.

Fuel efficiency and environmental performance. CO_2 emissions from vehicles are reduced along with fuel consumption. Even for technology-dependent pollutants such as NO_x, CO and HC, experience gained during the 1970s and 1980s in the United States suggests that the dual goals of lower emissions and higher efficiency are largely compatible, as shown in Figure IV.3. These achievements are nevertheless not sufficient to meet stringent emission regulations. In the case of gasoline-fuelled vehicles, NO_x problems have been tackled by the introduction of three-way catalytic converters, though there remain CO cold-start problems that need to be addressed.

The diesel engine is facing specific environmental problems. Tests indicating that particulate emissions from diesel engines could be carcinogenic, though controversial, are causing concern. At present, attention in this respect has centred on heavy goods vehicles, but an increase in the number of diesel-powered cars would become an issue as well. Diesel cars cannot be fitted with catalytic converters and NO_x emissions from diesel engines may be above the level fixed in future emission regulations. For instance, a proposed EC directive extends stricter NO_x standards to all passenger cars irrespective of size or type.

Figure IV.3
US Emissions and Fuel Economy Trends



Nevertheless, the attention being given to the quality of diesel fuels by legislators, refiners and automobile manufacturers may contribute to improving the outlook for diesel-fuelled vehicles. Cleaner, higher-quality diesel fuels will allow more efficient engine performance with reduced emissions (DRI, 1989).

The reduction of emissions from diesel and lean-burn engines must confront the tradeoff between environmental performance and fuel efficiency. This debate first appeared over the question of the fuel economy penalty of add-on pollution control technology for gasoline-fuelled vehicles. The size of the penalty involved is variable and the subject of debate. For instance, the fuel consumption of a car equipped with a three-way catalytic converter is likely to be 5-10% higher than for a non-equipped car, though improved converter designs and the use of electronic fuel injection can offset this fuel economy penalty (OECD, 1988). Some car manufacturers therefore do not anticipate a fuel economy penalty from the introduction of catalytic converters. In the car fleet as a whole, the requirement for electronic fuel management systems in conjunction with three-way catalytic converters will force some older engine types out of production. The fuel economy penalty of catalytic converters is often contrasted to the energy benefits of the lean-burn engine, which can reduce fuel use 20% and NO_x emissions 80%, compared to the emission reduction performance of 90% offered by three-way catalytic converters (which cannot be fitted to lean-burn engines). As a result, lean-burn engines may not be able to meet recent, more stringent emission standards such as those adopted by the EC in 1989.

Because diesel-fuelled passenger cars cannot be fitted with catalysers, tighter NO_x emission standards may push them out of the market. Compared to gasoline-fuelled cars, diesel-fuelled cars, in addition to their energy benefits, usually offer lower CO, HC and NO_x emission levels (though they entail higher particulate emissions, which have become the focus of health concerns). In the past, diesel-fuelled vehicles have often benefited from relatively relaxed standards, in recognition of their energy performance and of the specific problems that diesel engines pose in meeting strict standards for both NO_x and particulate matter. Particulate emissions can be reduced 40-60%, but this tends to increase NO_x emissions. Europe, where diesel-powered vehicles held 18% of the new vehicle market in 1986, has lagged behind Japan and the United States in controlling diesel pollution. The stringency of NO_x emission control regulations for diesel-fuelled cars is now catching up with the levels of requirements applied to gasoline-fuelled cars.

Technical improvements for goods vehicles. In the case of light goods and service vehicles (unladen weight up to 1 525 metric tons) much of the new technology discussed above for passenger cars will be applicable. Heavy goods vehicles traditionally have direct injection diesel engines. There is relatively little scope for improvement in fuel consumption in this type of engine since a great deal of research and development has already taken place. Turbocharging and aftercooling, which are becoming increasingly common, have the effect of improving power output and fuel efficiency in heavy diesel engines. It has been estimated that improving other engine features, such as internal friction and engine weight, could improve fuel economy about 5% over the next few years. Continuously variable transmissions might save 10-15% of fuel consumed. Improved aerodynamics could contribute fuel savings on the order of 20-30% at highway speeds. Further weight reductions through the use of lightweight materials for cabs, fuel tanks, air reservoirs and certain structural parts could result in average savings of 3-5% (Fergusson and Holman, 1990).

Finally, turbo-compound diesel engines are being developed to improve fuel consumption, as the thermal insulation around the engine reduces heat loss due to the coolant and the additional energy in the exhaust gases is extracted using an efficient turbine. Many of the technical changes in heavy-duty vehicles over the next few years are likely to be related to the imposition of more stringent emission standards. For instance, in order to meet the 1991 US standards for CO, HC, NO_x and particulate matter, new heavy-duty diesels will need to be turbocharged and intercooled, have higher compression ratios and improved combustion and use sophisticated high-pressure fuel injection systems.

Estimation of overall technical potential for fuel efficiency improvements. The estimates of fuel consumption benefits provided in Table IV.28 are given for individual technologies and the benefits of more than one technology combined are not necessarily cumulative.

There is a very broad range of technological improvements that could significantly improve the fuel efficiency of light vehicles before the turn of the century. How they may be combined into a single, more efficient vehicle can to a large extent be seen from existing high-efficiency prototypes vehicles (shown in Table IV.29), which, though they do not represent the bounds of technical feasibility, incorporate many of the technological improvements discussed above. From a fuel efficiency standpoint, the most advanced passenger car prototype is the Toyota AXV, with fuel consumption of about 2.4 litres/100 km. In terms of emissions, safety and fuel efficiency, the LCP 2000 prototype produced by Volvo is particularly promising. It passes the most stringent crash and emissions test and achieves fuel efficiency of 3.6 litres/100 km.

The impact of this research on the fuel economy of real vehicles is difficult to assess, as is its time frame. A survey of the literature reveals that analysts agree that a significant technical potential exists to improve the fuel efficiency of new vehicles, but the figures given for this efficiency improvement are between 10% and 40%. This wide range of estimates for the possible fuel efficiency improvements offered by technology that is available and well known is often due to different baseline references. Baseline figures refer sometimes to average new vehicle efficiency and sometimes to the efficiency of existing stock. The average new vehicle being marketed now is about 30% more fuel efficient than the average vehicle in service. There are still considerable regional differences, particularly between the European and Japanese markets and North America, where the efficiency is lower but the potential larger. Some studies include changes in vehicle attributes (acceleration performance, interior room, power options). Average engine size is increasing in vehicle sales in many IEA countries, despite the fact that cars with smaller engine capacities have the lowest fuel consumption. Today's cars are usually optimised for open road and highway driving, though surveys in Europe show that about half of car mileage takes place in urban areas. The user would have to accept any loss in performance from smaller engine size in order to gain the energy efficiency benefits.

There is scope, nevertheless, for improved fuel efficiency in passenger and goods road transport without sacrifice of vehicle performance. The magnitude of the changes that can realistically be included also depends on the time scale considered. For shorter-term estimates, it can be argued that technology that is available but would require major changes in car manufacturing procedures should not be taken into account, since the lead time for the development and commercialisation of new models is at least five years and major engine changes would take even longer, as manufacturing chains would have to be modified.

Table IV.28

Technologies Available for Improved Fuel Consumption in Gasoline Cars

	Technology	Fuel Consumption Benefits (% Relative to 1986 Gasoline Engines)
Conventional Engine Design	Improvements to gasoline engines (e.g. precision cooling, reduced engine friction and pumping losses)	up to 6%
Power Plant Design	Lean burn engines, 4-valve/cylinder	5 to 15%
	Direct injection 2-stroke gasoline engine	0 to 10%
	Electronic engine management	5 to 20%
Vehicle and Transmission Design	Transmission improvements (e.g. automated manual)	10 to 15%
	Continuously variable transmissions	10 to 15%
	Weight reduction	15 to 20%
	Aerodynamic improvements	5 to 10%
	Improvements in tyres, lubricants and accessories	5 to 10%

Source: Energy Efficiency Office, 1989.

The short-term (1995) potential was estimated in a recent survey of published papers on energy efficiency to be 5-8% of the consumption of European gasoline-fuelled cars (Bleijenberg and Rutten, 1990). According to the UK Energy Efficiency Office, the net effects by 2010 on the average fuel consumption of cars are estimated to be on the order of 12.5% for gasoline-fuelled cars and 15.9% for diesel-fuelled cars, applied to a baseline 1986 average fuel efficiency of 9.6 and 6.9 litres/100 km respectively. These figures are in line with improvements observed over the last 20 years (about 1% per year on average). A recent report for the Netherlands indicates that a higher technical potential of about 24% would be possible in 2010, compared to 1985 fuel efficiency (Blok *et al.*, 1990). If one also includes changes such as weight and engine power reduction, the figure for fuel economy improvements could increase to 30-40%. Changes in vehicle design and reductions in mass, aerodynamic drag and rolling resistance, together with better matching of engine and transmission for fuel economy and, most important, the use of higher-efficiency engines, could combine to give a car with a fuel consumption less than 60% of today's average — from 7-9 litres/100 km to 4.5-5.5 litres/100 km (Bleviss, 1988), though this would not be possible before the turn of the century. The most likely figure for improvements by 2000 (bearing in mind the lag times inherent in the commercialisation of vehicles) without changes in vehicle attributes is 15% in Europe and Japan and 20% in North America, though if diesel cars were to be replaced by gasoline cars the figure would be lower. A study for Denmark has found that the efficiency of passenger cars can be improved to 4 litres/100 km by 2010 and to 2 litres/100 km by 2030 (Danish Ministry of Transport, 1991).

Table IV.29

High Fuel Economy Prototype Vehicles

Company	General Motors	British Leyland	Volkswagen	Volkswagen	Volvo	Renault	Renault	Peugeot	Peugeot	Ford	Toyota
Model	TPC (gasoline)	ECV-3 (gasoline)	Auto 2000 (diesel)	VW-E80 (diesel)	LCP 2000 (diesel)	EVE + (diesel)	VESTA2 (gasoline)	VERA - (diesel)	ECO 2000 (gasoline)	- (diesel)	AXV (diesel)
Number of passengers	2	4-5	4-5	4	2-4	4-5	2-4	4-5	4	4-5	4-5
Aerodynamic Drag Coefficient	.31	.24-.25	.25	.35	.25-.28	.225	.186	.22	.21	.40	.26
Curb Weight (kg)	472	662	778	698	705	853	475	700	458	850	649
Maximum Power (hp)	38	72	53	51	52.88	50	27	50	28	40	56
Fuel Economy (L/100 km)	3.9 city 3.2 hwy	5.9 city 4.5 hwy	3.8 city 3.3 hwy	3.2 city 2.4 hwy	3.8 city 2.9 hwy	3.8 city 2.9 hwy	3.0 city 2.2 hwy	4.2 city 2.7 hwy	3.5 city 3.2 hwy	4.1 city 2.6 hwy	2.6 city 2.2 hwy
Innovative Features	Aluminium body and engine	High use of aluminium and plastics	DI with plastic and aluminium parts, fly-wheel stop-start	Modified DI 3-cyl. Polo, fly-wheel stop-start, super-charger	High magnesium use; 2 DI engines developed, 1 heat insulated	Supercharged DI with stop-start	High use of light material	DI engine, high use of light material	2-cylinder engine, high use of light	DI engine	Weight is 15% plastic, 6% aluminium, has CVT and DI engine
Development Status	Prototype complete, no production plans	Prototype complete	Prototype complete	Ongoing research, possibility of production	Prototype complete, adaptable to production	Prototype complete	Programme completed	Ongoing development	Ongoing development	Research	Ongoing development

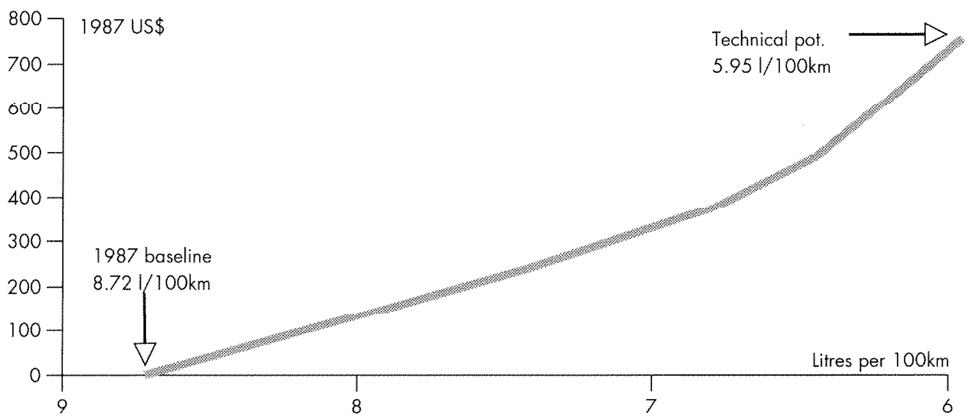
Notes : DI = direct injection. hwy = highway. CVT = continuously variable transmission.

Sources : Based on Johansson and Williams, 1987; Bleviss, 1988; and Delsey, 1990.

Costs. Manufacturers can pursue fuel economy in many ways, with different implications for the price and attributes of the vehicle. The costs associated with the fuel efficiency improvements described above can be as high as $2 300 per car (US Environmental Protection Agency, 1989), though lower costs are more likely. New fuel-efficient technologies usually cost more, but they can be offset by other benefits, for which consumers may in fact be prepared to pay more. For instance, research is under way to allow ultralean-burn engines to meet air quality standards with the use of three-way catalytic converters. The cost of improved fuel efficiency can also be offset by streamlining other costs — in fabrication, for instance. The Volvo LCP 2000 prototype, which has fuel consumption of 3.6 litres/100 km, was designed to cost, in theory, about the same to manufacture as an average subcompact car at a production level of 20 000 cars per year, though this production was not carried through (Mellde, 1986). In a computer analysis of the cost of introducing a number of improvements designed to lower fuel consumption from 5.2 litres/100 km to 3.3 litres/100 km, the cost was estimated to be about $500 per car (Von Hippel and Levi, 1983). Other sources refer to a cost of $200 to $500 for significant (15-30%) fuel efficiency improvements, compared with an average vehicle cost of $10 000 to $15 000. This does not mean that the technology will be perceived as being cost-effective by consumers, but rather that it is affordable in the overall context of transportation expenditures. Figure IV.4 shows the relationship between fuel economy levels and cost increases on the basis of data calculated in a recent study by Difiglio, Duleep and Greene (1989) compared to a 1987 baseline for domestically produced new passenger cars in the United States, which had average fuel efficiency of 8.7 litres/100 km. For the maximum technical potential, which in this study is estimated at 5.95 litres/100 km, the cost would be $756 per car in 1987 dollars, without changing the size and performance of passenger cars.

Figure IV.4

Cumulative Cost of Achieving the Technical Potential for Domestically Produced Passenger Cars in the United States



Operational changes. In the short term, the greatest potential for fuel economy in the road transport sector lies in operational changes, i.e. changes in the way vehicles are used and driven. Fuel consumption is optimised when a well-maintained vehicle is driven by a light footed user in free-flow traffic conditions. The influence of driving pattern and technique is substantial and the variation from one driver to another can represent over 20% of fuel consumption (Neumann, 1989). Trained, economical drivers can use 50% less fuel than the national fleet average (OECD, 1986). Tests show that if drivers can be made aware of good driving habits like moderate acceleration, anticipation of braking and travelling at moderate speeds, some 10-15% of car fuel could be saved (Redsell *et al.*, 1989). There is an abundant literature on the effect of driver behaviour on fuel consumption and most IEA governments publish information manuals on fuel-efficient driving. Several countries have included mandatory fuel-efficient driving training in driving licence requirements. Fuel savings through improved driving are not only a question of skill, but also of habits and attitudes, which are very difficult to change.

In addition, professional maintenance is essential to ensure the optimisation of the fuel consumption of a vehicle, as well as increased reliability, a reduction of polluting emissions and greater road safety. The size and complexity of the car design and manufacturing industry contrasts sharply with the attention paid to the training and equipment of maintenance specialists. The average driver is usually aware of this situation and is reluctant to rely on maintenance and repair shops for preventive maintenance. This neglect has a high fuel cost, as surveys such as the one carried out in Spain in 1989 reveal: 60% of the vehicles examined were using over 30% more fuel than well-maintained vehicles (Alonso, 1989). Some of these problems will diminish as electronic ignition and computerised control become more common, but others remain largely under the control of the driver.

Medium/long-term options. In terms of R&D, two achievements could have a strong effect on fuel efficiency: a catalyst (applied to the engine or exhaust) that could work with a broader range of mixtures and could be used with lean-burn or diesel engines; and the development of stratified-charge engines. The time frames for the development of these technologies, for which leads exist, are not known. Alternative designs of heat engine, such as two-stroke spark ignition engines, Stirling engines and Brayton cycle engines, together with electric motor drives and hybrid vehicles, have been studied extensively. From a technical viewpoint, the performance of unconventional heat engines does not yet match that of conventional engine designs and experience with methanol-fuelled vehicles that were supposed to be a relatively easy extension of conventional technologies indicates the scale of the difficulties involved in large-scale shifts towards alternative fuels and automotive options. For example, two-stroke engines have poor fuel consumption at medium and full loads and would need an exhaust catalyst because of high HC emissions. Stirling engines require the development of heat exchanger materials that can meet the reliability and durability of motor vehicle use. Brayton cycle engines have poor part load efficiencies and require advances in high-temperature ceramic materials, though they are probably closer than the Stirling engine to successful application because they are likely to benefit from R&D in other areas (Santini, 1985). Electric motor traction suffers from the lack of high-density batteries that can operate at ambient temperatures. Flexible fuel vehicles could bridge the gap between the introduction of a new fuel and the development of the necessary infrastructure. Improvements in storage systems and efficiency are in any case vital to increasing the range of alternative fuels such as CNG.

(b) market barriers and potential

As noted above, there is significant technical potential to improve the fuel efficiency of new vehicles, though there is a very wide range of estimates for related overall fuel economy improvements. The translation of this technological potential into market potential poses further problems, relating to the assumptions that are used to describe real or hypothetical market conditions.

These problems are illustrated, for instance, by the recent debate in the United States about gains in fuel efficiency from technological improvements, which has centred on a report prepared for the Department of Energy by Energy and Environmental Associates (EEA). EEA developed projections of fuel economy for 1995 and 2001 for three scenarios representing different technologies and levels of market penetration:

- Scenario 1 follows the "product plan" of car manufacturers and assumes changes in the market due to fuel prices or legislation.

- Scenario 2 is based on "maximum available technology" — estimates of the maximum fuel economy level attainable if manufacturers were forced to introduce the best available technology.

- Scenario 3 is a hypothetical maximum case similar to scenario 2, but with vehicle attributes held constant at 1987 levels.

The EEA report estimates a possible 17.1% improvement in the fuel economy of new cars between 1987 and 1995 for scenario 1, despite the current lack of marketplace demand for fuel-efficient vehicles. For 1995 to 2001, the EEA estimates additional improvements of 9.9% for scenario 1, 17.2% for scenario 2 and 27.6% for scenario 3. US auto manufacturers suggest, however, that lower levels of fuel economy are associated with the various technologies. Where the EEA estimates a 17.1% improvement in the near term, Ford, General Motors and Chrysler estimate 7.1-8.6%, and, for 1995 to 2001, 2.8-3.4% for scenario 2 and 13.8-14.6% for scenario 3 (Bischoff, 1990).

Beyond basic disagreements on the level of fuel economy associated with the development of new, more fuel-efficient technology, it is clear that here, as in many similar analyses discussed in the United States and elsewhere, there are broad differences in assumptions about the market factors affecting the penetration of such technology. A lot can be learned by observing past and current market conditions and how they have affected the introduction of this kind of technology. For instance, the Citroen AX gasoline-fuelled passenger car was based on a prototype that consumed 3 litres/100 km, and for which mass production was considered possible with consumption of 4.3 litres/100 km. In the absence of consumer demand for this type of car, the most efficient Citroen AX brought onto the market had average consumption of 5 litres/100 km. It could be said that the technical fuel efficiency potential for this category of vehicle, using available technology, was 3 litres/100 km, and that its market potential, for the type of consumer likely to purchase this category of passenger car, was 5 litres/100 km. These figures can be compared to the average 1988

European new car consumption of about 7.8 litres/100 km and average fleet consumption of 9.2 litres/100 km. The nature and impact of the market factors that explain these different figures, and are also likely to affect future developments, are the focus of the discussion presented below.

New engineering ideas are developed and incorporated into vehicles as a result of a variety of market factors. Automakers may need to respond to a dramatic change in their market and to develop new design approaches to cope with such a change. An example is the introduction of more stringent emission regulations and the development and introduction of control technology. Another factor is competitive innovation, when consumer demand for certain features is strong and/or when there are many manufacturers at a high level of technical expertise competing in a relatively mature market. During the 1970s, when fuel consumption was a major concern of vehicle users, manufacturers responded by deploying technology aimed at limiting fuel consumption. Changes can also result from exogenous developments of new technology with applications in the road transport sector. An example is the use of microprocessor technology, which can be incorporated into engine systems.

The eventual market penetration of new technology depends on the rate at which older vehicles are scrapped, but the speed of the major car manufacturers in identifying a market need and reacting to it is crucial. Economic growth and fuel price changes may nevertheless modify average penetration rates. For instance, economic growth will accelerate stock replacement and, probably, technological change. The US National Energy Strategy, announced in 1991, identifies measures to accelerate the scrappage rate of older cars as a priority area for reducing emissions and improving the average fuel efficiency of the fleet (USDOE, 1991). The rate of diffusion of technology also depends largely on whether the innovation requires a major change in manufacturing operations. Experience shows that major innovations that are sophisticated and capital-intensive require, on average, about 15 years to achieve half of their potential market (this was the case for the penetration of diesel fuels into commercial vehicle operations, from the 1950s onwards). Incremental innovations that are technologically simple and relatively cheap will require about five years on average to achieve a similar level of penetration (as shown, for instance, by the introduction of the five-speed gearbox as a standard item for new cars). Compared to the lifetime of buildings, industrial plants and equipment, the ten-year life of an automobile is relatively short, so decisions to increase the efficiency of the stock take a shorter time to realise fully than in other economic sectors.

The nature and rate of penetration of improved energy efficiency technology are determined to a large extent by the market for new cars. Cars have an average lifespan of ten to 14 years; heavy goods vehicles, used more intensively, last about eight to ten years on average. In the United Kingdom, 9% of the car population is over twelve years old and about 40% is under four years old, while 16% of the heavy goods vehicle population is more than eight years old and nearly 50% is less than four years old. The car scrappage rate implied in these figures does not allow a very rapid rate of introduction of technical innovation, though the effect on fuel demand can be more immediate because newer cars have higher mileage. The higher turnover rate of heavy goods vehicles means that once a new design is introduced into the market, its penetration rate can be more rapid. However, many heavy goods vehicle operators require proven reliability of new technology over a life of 800 000 km. In addition to the effect of vehicle turnover, net increases in stocks and traffic will also affect the penetration rate of new technology and resultant fuel consumption. In the United Kingdom, the stock of private cars is likely to increase 17-19% between 1987 and 2000, which will bring about an increase in traffic (expressed in vehicle-kilometres) on the order of 15%.

In most IEA Member countries, at least ten domestic and foreign car manufacturers are active in the market. It is generally recognised that this is a very competitive market sector. In addition, legislative requirements, such as those relating to emission controls or road user safety, impose technical constraints on car design and operation. Manufacturers attempt to stimulate demand and extend market share by, for example, promoting technical innovation of a given type. If competition is very sharp and if the leading firms adopt a strong technical orientation in choosing areas in which to compete, then the rate of penetration of new technology could be very rapid. Despite lower consumer demand for fuel economy, companies continue on a substantial scale to explore new fuel-efficient technology, as it delivers many benefits, of which fuel economy is but one. However, consumer acceptance of these improvements is determined by their perceived value against competing vehicle attributes. The technical arguments in favour of improved fuel consumption may not be sufficient to ensure that the savings are achieved. This is substantiated by consumer behaviour over the last few years and the trend towards larger, more powerful cars throughout the OECD. In recent years, technological breakthroughs in vehicle and engine design, once developed as a marketable product, have been used to give drivers more power rather than the same power with lower energy consumption. The case of turbocharging technology is, in this respect, typical: This breakthrough could have been used either to improve fuel efficiency at constant power or to supply the driver with more power (and increase fuel consumption).

Fuel prices and costs. Estimating how much of the technical potential for improved fuel efficiency is likely to be translated into the market is not straightforward, because even if information about capital costs and energy savings is available, the cost-effectiveness of energy efficiency improvements means little to most actors in the market. Whereas technical potential for improved fuel efficiency varies according to the type of vehicle considered, the market potential for these improvements depends largely on whether the vehicle is operated as part of an economic activity or is for private use. When the vehicle is used privately, it is important to recognise that cars are not solely process machines and are usually not regarded as such by their owners. Thus, any analysis of the cost-effectiveness of energy efficiency improvements in the private motoring sector has to recognise non-financial costs and benefits. Where the vehicle is used as part of an economic activity, energy expenditure represents part of the cost of running the operation. Though fuel might represent the same share of costs, the attitude to savings depends on the size of the operation: The larger the transport company or undertaking, the more rationally savings are assessed. In addition, not all transport equipment is operated by the owner. Many operators are relatively small companies that still see first costs as the principal determining factor in their investment decisions. Few operators are prepared to consider life-cycle costs as the appropriate costing methodology. Public transport such as buses, commercial transport and company cars are usually operated by employees of the owning organisation. Responsibility for fuel costs does not usually lie with the drivers. Hence the attitudes of operators to energy efficiency vary and depend on such diverse factors as individual motivation, industrial relations, training and level of professional skill, and the balance between minimising fuel consumption and maintaining standards of service.

In theory, higher fuel prices should bring consumer demand for fuel economy, and this in turn prompts car manufacturers to improve the efficiency of vehicles launched onto the market. But this assumption model needs to be examined more closely. Fuel costs influence fuel consumption in two ways. As a major component of the variable cost per kilometre of travel, fuel prices directly influence the demand for vehicular travel. Fuel prices also affect the fuel efficiency of the vehicle stock. In the short run, the effect of higher fuel prices is almost entirely reduced travel (USDOE 1987). Over a longer period, more efficient new vehicles replace the older stock, decreasing specific consumption and reducing total fuel use. Other factors, such as relocation of residences and workplaces, or shifts to less energy-intensive transportation modes, are also affected by fuel prices, but the size of these changes has not been found to be significant in comparison with the effects on travel and fuel economy.

Assuming the existence of price-induced consumer demand for more efficient vehicles, manufacturers are left with the problem of choosing what level of efficiency consumers will respond to. The "invisible hand" of the market should direct manufacturers to produce vehicles with characteristics that consumers desire and will pay for. In theory, cost-effectiveness depends on the price the consumer is prepared to pay for the technology and the present value of the fuel cost savings it will produce over time. The estimated value of the savings reflects the consumer's discount rate and expected vehicle use. But consumers, in their quest for fuel economy, generally do not make a strictly rational economic calculation of the level of economy they want. A recent US study of the cost-effectiveness of future fuel economy improvements (Difiglio, Duleep and Greene, 1989) discounted fuel cost savings at rates taken to approximate consumer behaviour. It assumed that car buyers discount fuel savings at a real rate of 10% a year over the first four years of the car's ten-year life. This is consistent with implicit discount rates in the range of 20-30%, found in other studies, for savings over the full life of the car.

Some manufacturers have tried to rationalise the level of fuel economy increase they should offer. For example, Fiat requires a two-year payback on any efficiency innovation it introduces. But such attempts at rationalisation may not be any closer to reality. For instance, after the 1979/80 energy crisis, American buying decisions were often based more on qualitative assessments such as the size of the car rather than quantitative assessments such as the results of fuel efficiency tests (Bleviss, 1988).

A 1984 study for the US Department of Energy (Cheslow, 1984) throws some light on how much consumers were prepared to pay for improvements in fuel economy, operation and service. The results, summarised in Table IV.30, show that the average value attributed to a fuel economy improvement of one mile per gallon was lower than those attributed to a range of other performance and service improvements.

Table IV.30
Apparent Value of Automobile Attributes

	Range in US$
One mile per gallon	15 to 150
One second 0 to 40 miles per hour	45 to 500
Increase range by 50 miles	100 to 1 000
Increase seating from 4 to 6	800 to 7 000
Increase length by 6 inches	0 to 1 300

Source: Cheslow, 1984.

Beyond the difficulty of translating consumer demand into fuel economy improvements, manufacturers face the problem of not being able to respond rapidly to that demand. Relatively minor adjustments can be made immediately, but noticeable improvements in fuel economy can really come only with the introduction of new models. It takes about five years to bring new models into production, from earliest design to final tooling for manufacture. Furthermore, it is not reasonable to expect a manufacturer to redesign all production lines at once, as this would require high investment levels and the scrapping of capital equipment.

Conclusions. R&D efforts are taking place across a very wide range of technologies. Technologies that have resulted from these efforts or are still under development have the potential to reduce fuel consumption significantly. But two major failings need to be addressed if the fuel economy of the fleet is to improve: The fruit of this research is being put into production neither as soon nor as broadly as possible, and vehicle users are not receiving the message that fuel economy is important. The market may encourage fuel economy if fuel prices increase or if fuel economy is emphasised as a competitive feature. In the absence of a fuel price incentive, the introduction of technical innovation can generally be regarded as resulting from the competitive environment in which manufacturers choose to operate, rather than deriving from consumer demand. If it happens that fuel efficiency is not the area where manufacturers are competing, the last option available to decision makers is to use policy instruments to accelerate changes in the efficiency of vehicles.

The role of governments in encouraging the transition to more fuel-efficient vehicles must be carefully thought out. Policies that conflict with market conditions or that overregulate the industry may prove counterproductive. Policy options and instruments that may avoid these pitfalls are examined in detail in the following chapter. The first role governments may play is to encourage research on fuel economy. In recent years, governments in France, western Germany, Italy, Sweden and, indirectly, the United Kingdom have funded prototype fuel economy projects. These projects have spurred investigations into technologies such as advanced aerodynamics, new material applications, lean-burn combustion techniques and direct-injection diesel designs, and have served as a basis for the production of vehicles with new fuel economy features. Finding a policy tool that works is difficult, and once a tool has proven successful, it merits reconsideration in the future. These programmes could in fact be improved by having sets of minimum criteria, not only for fuel economy, but also for size, safety, emissions, performance and ease of manufacturing, to ensure that these prototypes have commercial applicability.

Even with active government involvement in setting long-term fuel economy research priorities, these efforts will have little effect unless the fruits of research are carried into production. Production incentives can include voluntary targets for fuel efficiency. As in any market-based economy, incentive for vehicle manufacturers to change the nature of their fleets can only go so far. If consumers are unwilling to purchase these new cars, manufacturers will be unwilling to produce them. Thus, to be successful, government policies to encourage interest in fuel economy among producers will need to be supplemented by similar programmes for car buyers. These issues, and others relating to policy options and instruments, are examined in Chapter V.

3. OVERVIEW OF ENERGY EFFICIENCY OPPORTUNITIES

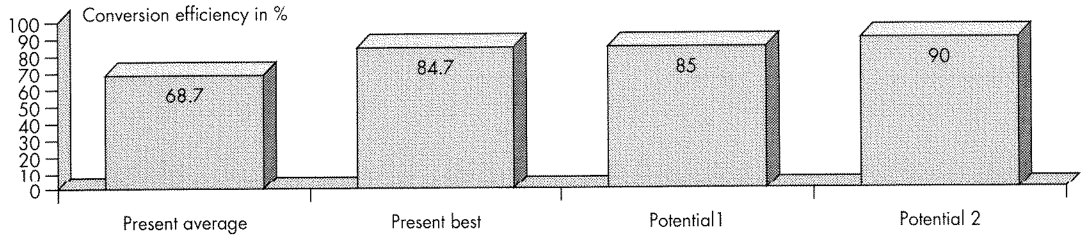
A major conclusion to be drawn from the analysis presented in sections 2.1 to 2.4 of this chapter is that in virtually all sectors and for all major end-uses, the improvement in energy efficiency observed over the last 15 years is set to continue because the efficiency of new equipment available on the market is usually better than that of the average stock. Past and current improvements in the efficiency of energy-using equipment, from passenger cars to domestic appliances, have yet to be fully felt and the faster the stock turnover, the better. Economic growth and the health of the economies of IEA countries can play a major part not only in accelerating the rate of turnover of existing equipment, but also in sustaining the technological creativity of industry that fuels the development of energy efficiency.

In addition to this structural potential for energy efficiency improvement, the analysis reveals that there is a major technical potential for further improvements in technologies that are readily available but are as yet little used for a variety of reasons, mostly relating to market conditions and consumer behaviour. Finally, additional improvements can be reached in the longer term, using advanced technology or technology that modifies equipment attributes in ways that would not be acceptable in present market conditions, as the level or quality of service might be altered. Figures IV.5 to IV.15 summarise these opportunities for a range of end-uses in industry, transport and the residential and commercial sectors.

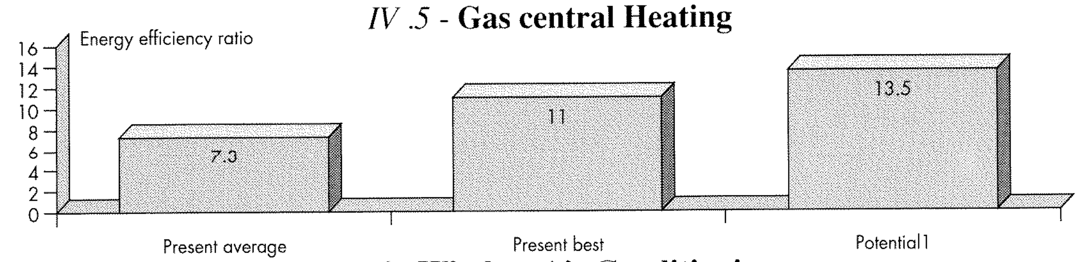
More work is needed on the cost-effectiveness of the investments these energy efficiency opportunities would require. In cases where cost data are available and estimates have been provided, the cost-benefit analysis presented is country-specific because energy prices vary markedly from one IEA country to the next (see, for instance, Figure III.20 on gasoline prices and Figure IV.2 on electricity prices and their effect on efficiency costs) and because the price of energy-efficient equipment is also extremely variable (the purchase price of aCFL can be as low as $8 or as high as $44). In many cases, a broader range of case studies is needed for meaningful IEA-wide cost-benefit analysis. Nevertheless, the analysis in Chapter IV includes a comprehensive assessment of the factors that influence consumer

Figures IV.5 to IV.15

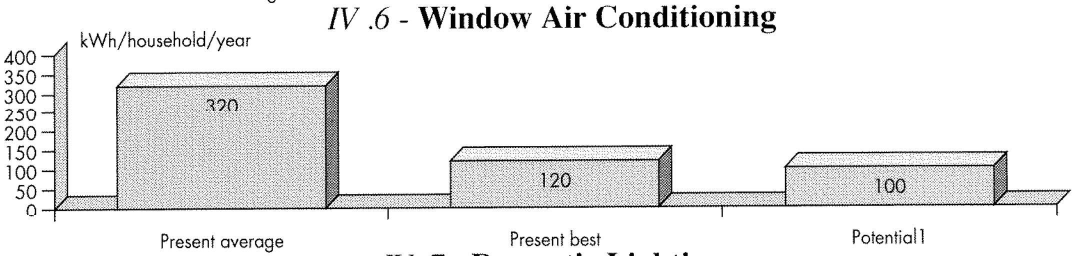
Potential for Energy Efficiency Improvements for a Range of End-Uses in Buildings, Industry and Transport



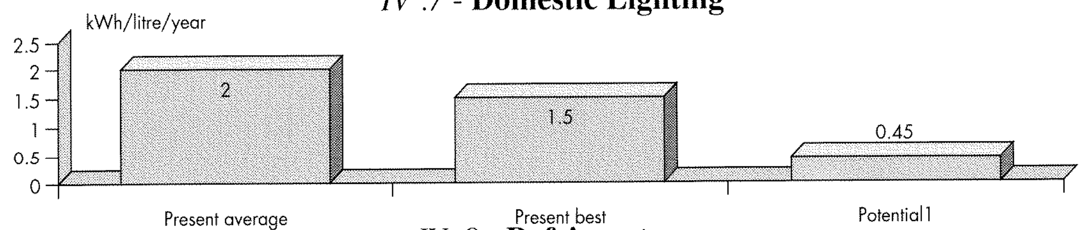
IV .5 - **Gas central Heating**



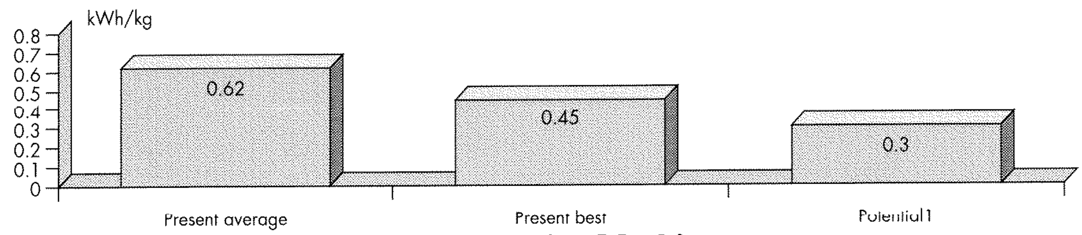
IV .6 - **Window Air Conditioning**



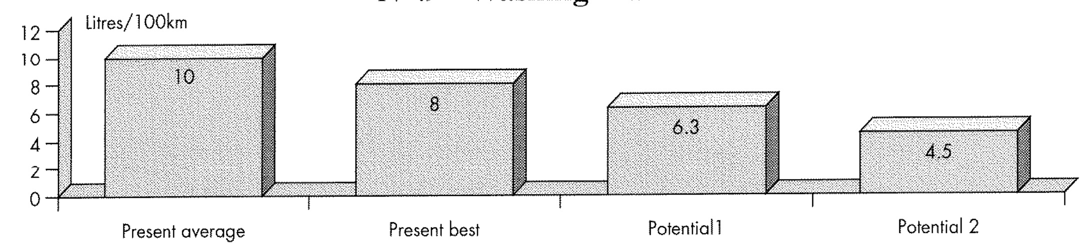
IV .7 - **Domestic Lighting**



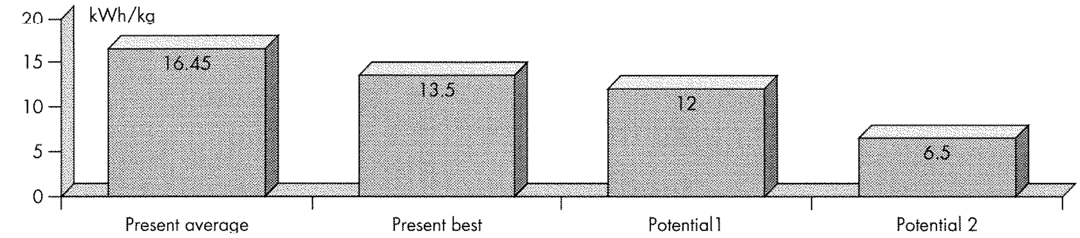
IV .8 - **Refrigerators**



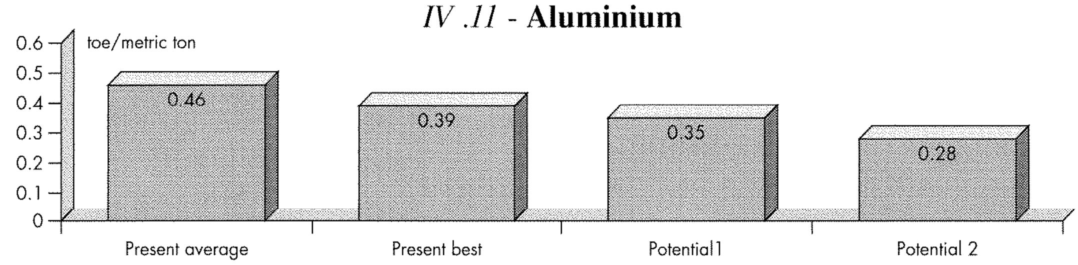
IV .9 - **Washing Machines**



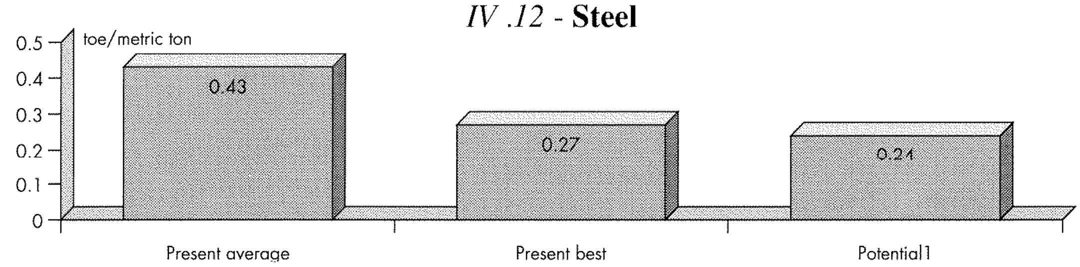
IV .10 - **Passenger Cars**



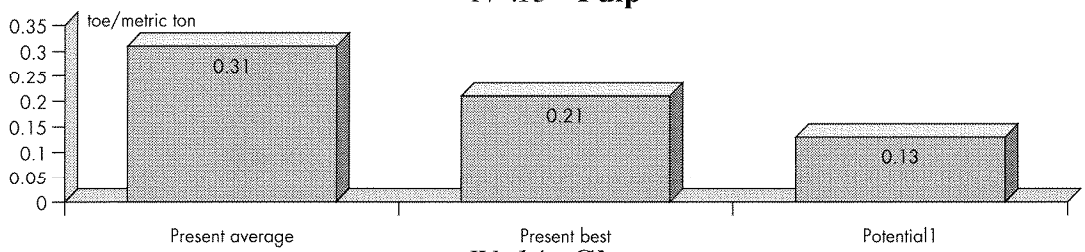
IV .11 - **Aluminium**



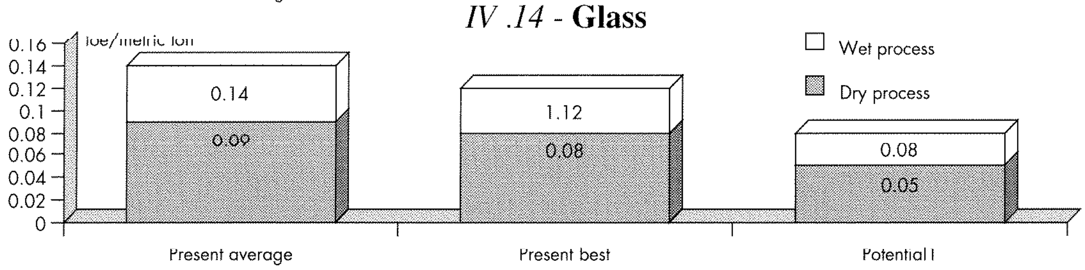
IV .12 - **Steel**



IV .13 - **Pulp**



IV .14 - **Glass**



IV .15 - **Cement**

Notes on Figures IV.5 to IV.15

- All figures are averages for IEA countries based on the data provided in Chapter IV.
- Potential 1 represents the energy efficiency improvements obtained by integrating demonstrated state-of-the-art technology into current practice between today and 2005.
- Potential 2 is the maximum technical potential reached in 2005 at the earliest.

perception of energy costs and benefits and emphasises the importance of these factors to any assessment of marketconditions for energy efficiency improvements. As mentioned in several examples above, in some cases no additional costs would be involved and yet these savings are not being made. Many energy efficiency opportunities available today should in fact be already taken up by energy users if users were behaving in an economically rational way, even at present energy prices. Others would also require overcoming a range of technical and institutional barriers. On both points, the discussion of barriers has shown that perception of the real costs of energy use and access to technical information are key elements in developing energy efficiency improvements.

Table IV.31 puts these opportunities for energy savings into perspective by comparing them with the estimates of the share of energy use concerned and the degree of market and institutional barriers that need to be overcome. The examples included in this table account for nearly 70% of TFC and for over 71% of estimated total CO_2 emissions in IEA countries.

Table IV.31

Energy Efficiency Potential: Summary of Opportunities and Barriers

	(A) Estimated Share of Total Final Consumption	(B) Estimated Share of Total CO_2 Emissions	(C) Total Energy Savings Possible[1]	(D) Existing Market/Inst. Barriers[2]	(E) Potential Energy Savings not Likely to be Achieved[3]
Residential Space Heating and Conditioning	11.4%	11%	10-50%	Some/Many	Mixed
Residential Water Heating	3.4%	3.6%	Mixed	Some/Many	Mixed
Residential Refrigeration	1.1%	2.1%	30-50%	Many	10-30%
Residential Lighting	0.6%	1.2%	over 50%	Many	30-50%
Commercial Space Heating and Conditioning	6.1%	6.8%	Mixed	Some/Many	Mixed
Commercial Lighting	1.5%	3.4%	10-30%	Some/Many	Mixed
Industrial Motors	4.5%	9.0%	10-30%	Few/Some	0-10%
Steel	4.1%	4.6%	15-25%	Few/Some	0-15%
Chemicals	8.4%	5.9%	10-25%	Few/Some	0-20%
Pulp and Paper	2.9%	1.2%	10-30%	Few/Some	0-10%
Cement	0.1%	0.9%[4]	10-40%	Few/Some	0-10%
Passenger Cars	15.2%	13.7%	30-50%	Many	20-30%
Goods Vehicles	10.1%	9.1%	20-40%	Some	10-20%

How to read this table: For example, for lighting, over 50% per unit savings would result if the best available technology were used to replace the average lighting stock in use today over the next ten to twenty years. Some of these savings would take place under existing market and policy conditions. But due to the many market and institutional barriers, there would remain a 30-50% potential for savings that would not be achieved.

1.Based on a comparison of the average efficiency of existing capital stocks to the efficiency of the best available new technology. This estimate includes the savings likely to be achieved in response to current market forces and government policies as well as those potential savings (indicated in Column E) not likely to be achieved by current efforts.

2. Extent of existing market and institutional barriers to efficiency investments.

3.Potential savings (reductions per unit) not likely to be achieved in response to current market forces and government policies (part of total indicated in Column C).

4. Energy use only.

CHAPTER V

EXAMINATION OF POLICIES AND INSTRUMENTS

1. REVIEW OF POLICIES AND INSTRUMENTS

This chapter explores some of the policies and instruments that could contribute to achieving the energy efficiency potential identified in Chapter IV, their impact in terms of energy demand and emission reductions, their overall costs and their macroeconomic effects. If energy efficiency improvements are to make a substantial contribution to emission reductions, governments have a major role to play in applying policy instruments that can help bridge the gap between technical and market opportunities for improved energy efficiency. The first step in this analysis is to identify and examine conventional conservation policies and instruments that have been developed in IEA countries, mainly for energy security reasons. The analysis is extended to include a review of environmental control instruments in terms of their effect on energy efficiency and demand. The application of policy instruments is then translated into energy demand and emission reductions on the one hand and into costs for both the private and the public sector on the other. This leads to an assessment of the macroeconomic effect of such policies, for instance on GDP and inflation, as well as of the compatibility of these policies with broader economic and energy security goals.

1.1 Review of energy efficiency instruments: applications and effectiveness

All IEA countries have taken measures to support improvement in the energy efficiency of their economies, with varying emphasis on end-use sectors and policy options. The last 15 years, over which these efforts have been concentrated, provide sufficient historical perspective for an examination of these policies and of the instruments chosen to apply them. The review of energy conservation policies and instruments presented below focuses on:

- information programmes and energy management services;
- regulation and efficiency standards;
- pricing and fiscal policies;
- other economic incentive programmes;
- demand-side management (DSM);
- research, development and demonstration (R&D);
- the exemplary role of governments.

While markets respond more quickly and effectively to many economic problems than can government policy and regulation, market forces alone cannot always integrate the long lead times necessary to carry out energy supply and demand options. There is obviously a need for governmental measures to overcome the market barriers described in Chapter IV. To achieve this aim, policies focus on end-users or on equipment manufacturers. Governmental involvement in energy markets also extends to the proper regulation of natural monopolies. For instance, in the case of electricity and gas use in the residential, commercial and public services sectors, market forces and other factors that determine electricity end-use efficiency can be modified by the regulatory framework of utilities and by a range of environmental, energy security, fiscal and other policies that affect the allocation of economic resources. In designing more effective policies to encourage greater electricity end-use efficiency, there are at least four strategies that have been used by individual governments, depending on economic and political circumstances:

- modifying pricing and other utility regulations to ensure that correct price signals are given to electricity users;
- removing any limitations to utilities' carrying out DSM activities if these yield net benefits for both consumers and the utility;
- improving the effectiveness of market forces by ensuring that users have access to adequate information and advice;
- offsetting financial barriers to energy-efficient investments by offering selected, though usually temporary, financial inducements or by introducing carefully designed efficiency standards.

In developing and applying energy conservation policies, IEA Member countries have chosen different approaches, with different degrees of success. Given these variations and national geographic and economic differences, it is usually impossible to measure precisely which policy instrument has proven more successful than another or under which circumstances different policies work best. Even within a single country, those responsible for running energy conservation programmes have found it difficult to establish clear cause and effect relationships and attribute a given energy demand reduction to price effects, information efforts, financial support or standards. As a result, where programmes are evaluated, the assessment provided tends to be more qualitative than quantitative.

Two examples illustrate some of the problems of assessing the effects of policy measures. In order to increase the fuel economy of passenger cars, the US Government decided very early on to develop mandatory fuel efficiency standards. These standards have probably contributed to the noticeable improvement in the fuel economy of vehicles in the United States. Other countries, in Europe and in the Pacific region of the IEA, relied on the price effect and applied large taxes on gasoline, which contributed to significant efficiency improvements and reductions in the growth rate of gasoline consumption. The United States is also the only country that has enacted mandatory efficiency standards for residential appliances, which have caused substantial efficiency improvements, though it is not clear how much the standards actually contributed to efficiency improvements and how much would have been accomplished by market forces alone. There are also noticeable disparities in efficiency levels among IEA Member countries as a result of behavioural or economic differences. For example, standards planned in the United States for freezers mandate 1993 efficiency levels that are lower than the average energy consumption of comparable units in Germany in 1990[1]. This is partly a result of differences in design and service requirements.

These strategies and others can be pursued by the application of a variety of policy instruments, including information, regulation and economic instruments (Skinner, 1990). The degree of effectiveness of each policy instrument will nevertheless vary according to the target sector or end-use considered. These policy instruments are reviewed below and their applicability and effectiveness in IEA Member countries are assessed as far as possible.

(a) information programmes and energy management services

Information measures taken by governments can be broadly categorised as labelling, information campaigns, auditing, targeting or monitoring. They play an essentially supportive, though indispensable, role in energy efficiency strategies and are most effective when they promote actions that make good economic sense for the consumer. One of the main market barriers to consumer decision making in all end-use sectors is the lack of information on energy costs. Accurate, straightforward information that includes energy prices, investment requirements and possible energy savings is necessary to enable energy users to invest properly in energy-saving technologies and to overcome market barriers. But the prerequisite for such information is reliable data, which often has to be collected by surveys and analysis. Independent and credible testing of equipment and appliances is also required. In addition, if governments are going to institute other programmes, such as financial incentives, they need to know where the greatest potential lies and how best to stimulate a response to their policies.

Information campaigns have been addressed primarily to private residential and transport consumers, though sometimes industrial and commercial consumers have also been included. It is essential, for the success of information activities, to involve a range of other interested groups, such as professional and consumer organisations and industrial associations. In Austria and Switzerland, for example, associations of industrial energy consumers provide advice to members on energy-saving possibilities. In recent years, utilities have also become increasingly involved in energy-efficiency information initiatives as part of DSM programmes. The motivation for the most recent governmental initiatives stems from

1. The test procedures are not completely comparable as the US and German tests require different outdoor temperatures (32°C in the United States and 25°C according to DIN regulation).

concerns about the environmental consequences of energy production and use. For instance, the Dutch Government and electric utilities recently initiated information campaigns to enhance public awareness about the risk of climate change and opportunities to use energy more efficiently.

Information campaigns can be successful if they are carefully targeted; energy auditing programmes in industry or technical information manuals and guidelines for professionals, such as those prepared for architects in Switzerland, have had good results. In the United Kingdom, the Best Practice Programme supervised by the Energy Efficiency Office was established to publicise good practice in energy efficiency through, for instance, the organisation of workshops or seminars to spread information, guidance and advice. These events have also been used to publicise the results of demonstration projects conducted by the EEO in such areas as low-energy housing.

In a few countries, utilities and manufacturers have initiated programmes for a range of products to provide energy efficiency labels or similar information stating estimated comparative annual electricity costs. So far, Australia and, most notably, the United States have introduced the most comprehensive mandatory labelling systems covering most major home appliances. In Sweden, although it is not mandatory, *labelling* has become quite common. In response to initiatives by several Member countries the European Commission is considering extending its directive on energy labelling, which now covers only the labelling of electric ovens. The objective of this effort is to establish a Community-wide directive on efficiency labels and possibly minimum efficiency standards for major residential appliances.

Appliance labelling programmes, like information campaigns, are relatively inexpensive policy measures but in many cases they have not achieved the energy demand reductions expected, especially since energy prices have decreased. For example, in the transport sector, although most car manufacturers still provide information on fuel efficiency, consumers are more interested in cars' comfort and power than in fuel efficiency and are not responding to information alone.

Energy management initiatives, particularly in the industrial sector, gained importance in the years following the two oil price hikes and many countries emphasised the role of accountability in energy efficiency. This requires designating an energy manager within an organisation who is given the responsibility for the organisation's energy performance. Energy efficiency is viewed as a strategy for meeting business objectives and results are measured in terms of contribution to overall profit. Some Member countries, such as Japan and Austria, require each company to employ energy managers and to draw up energy balances. Such balances provide accounting data to facilitate the evaluation of energy conservation initiatives. Germany intends to provide further support for its existing energy consultancy programme for industry. In the United Kingdom, programmes of the EEO aim at stimulating the development and application of energy management skills and techniques on a regional basis.

Many Member countries have initiated programmes to provide *energy auditing* and consulting services to industry. The Energy Bus programmes of Canada and of the European

Community are one example. Energy problems in industry are as varied as industry itself, and energy audits or evaluation programmes have to be done in close co-operation with managers on site.

Targeting and monitoring of energy demand is another measure that can enhance energy awareness. Targets are sometimes considered conceptually helpful in focusing attention and interest on energy efficiency, providing they are chosen with care and are self-monitoring. They have to be flexible so that they can be adapted to economic variations, such as price changes and technological development. Targets can be voluntary or mandatory, set for specific enterprises or for certain industrial branches. For example, German car manufacturers entered into voluntary agreement with the Government in 1978 to reduce fuel consumption 15% by 1985 (the agreement expired in 1986). In fact, the target was substantially exceeded: Average fuel consumption was reduced almost 23%. The Canadian Industry Program for Energy Conservation linked over 650 participating companies through nearly 40 industrial associations, in co-operation with the Federal Government, to exchange information, conduct energy audits and make cost-effective energy efficiency investments designed to reach energy efficiency goals. In 1989, the programme achieved its goal of a 30% energy efficiency improvement over 1973 operating standards for Canadian industry as a whole. Similar initiatives have been undertaken in the United Kingdom in specific industries, though they were recently abolished.

(b) regulations and efficiency standards

Efficiency standards and regulations concerning energy-using appliances and installations have been introduced in most Member countries to overcome certain market barriers. As a result of country-specific circumstances, the sectors and appliances affected by such regulations vary markedly by country. They can be fairly effective and easy to promulgate, though their initial design often requires considerable technical knowledge and their development is resource-intensive. Standards need to be flexible to adapt to changed economic conditions, such as fluctuations in energy prices or technological breakthroughs, so that they do not reduce the incentive for industries to invest in research for more energy-efficient technology or fail to encourage the introduction of such technology. Rapid product diversification in certain end-uses can also make standard-setting difficult. If standards are not carefully set, they can lead to negative economic consequences, such as excessive production costs and higher costs for consumers. A study in the United States found that efficiency standards for electric residential appliances can lead in certain industries to profit reductions of up to one-third (Ruderman et al., 1990). Standards can also have other side-effects. For example, in some northern countries, buildings that are too airtight have had severe air-quality problems, leading to respiratory and other ailments. Air and heat exchange equipment investments then have to be made, sometimes leading to the otherwise unnecessary use of high-grade electricity in heat recovery.

The economic and energy effects of standards increasingly extend beyond national borders. The production of many appliances and cars is concentrated in a few countries and in a few companies. National standards can therefore affect the energy demand of countries to which products are exported. Efficiency standards can result in distortions of international trade and conflict with international harmonisation goals. As a result, international co-operation in this respect is important.

Standards and regulations are applied mainly to buildings, cars and residential appliances. Industry has usually not been covered by efficiency prescriptions for plants or equipment, because of reluctance about government involvement in industrial activities. More importantly, though, the level and scope of market barriers in industry are much lower than in private transport or residential buildings. This is particularly true for energy-intensive industries, where energy represents a significant part of operating costs.

Regulations in the buildings sector have been developed in many IEA countries, because energy requirements for space conditioning are responsible for over half of energy demand in the buildings sector and there are substantial market barriers to energy efficiency improvements in this sector. On the whole, standards have been particularly effective in the housing sector, as new buildings today typically use half the energy needed in the early 1970s. In recent years there has been a tendency to tighten these regulations, often because of environmental considerations related to energy demand for heating and space conditioning.

New building regulations in England and Wales were enacted in April 1990, with higher thermal insulation standards for all new buildings (residential, commercial or industrial). Compared with previous standards, the new requirements are expected to save about 20% of the energy required for space and water heating. They also provide a certain flexibility of design. As long as the overall energy demand that would result from prescribed efficiency levels is not exceeded, architects and designers need not comply with efficiency levels for individual building parts, such as walls or roof. In Sweden, new efficiency levels were adopted in January 1989. Thermal insulation codes were changed at the same time to allow more flexibility of design, much as in England and Wales. In Ireland, building standards are being reviewed in an effort to reduce heat demand in new houses by up to 15%, relative to current prescriptions, and by over 50% compared with the existing housing stock. Denmark and Germany are also considering more stringent building regulations.

In Denmark, planned codes for new buildings are intended to ensure that in 1993 the heat demand of new buildings will be 75% of present levels. The adoption of these building regulations will depend on their economic and energy impact, which will be tested in demonstration projects. The standards may be further tightened by 2000. Furthermore, a heat inspection is now required for residential buildings prior to sale. The vendor must give the purchaser a report showing energy performance and likely energy expenditures. The Swiss Federation of Architects has published recommendations on performance standards that require a certain level of energy performance for the whole dwelling and leave the design details to the architects. Such a regulation, which is similar to the new UK standards and those existing in Ireland, makes it possible to work out trade-offs between different parts of the building. By leaving the design to the professionals, flexible regulations clearly support market mechanisms.

Some regulations in the residential sector aim at increasing awareness of individual energy consumption and related costs in multifamily buildings. In several Swiss cantons, as well as in Germany and Austria, individual metering and invoicing of energy consumption for space heating and hot water is mandatory. Studies indicate that individual metering can lead to a reduction in energy consumption of 10-20%. In several countries, there are also regulations for boilers or requirements for periodic inspections of furnaces, though primarily for safety reasons.

The United States is the only country so far to have introduced *mandatory minimum efficiency levels for residential appliances*. The National Appliance Energy Conservation Act of 1987 (NAECA) specifies nation-wide energy performance standards for major energy-using household appliances and space conditioning equipment. Before these regulations were approved, issuing standards was the responsibility of the states. States that had enacted standards did so at different levels, leading to substantial regional differences in efficiency requirements. Although there was resistance from manufacturers to such harmonised federal standards, they were ultimately accepted because they eliminated these regional disparities. The standards, developed in consultation with the industry, are to be reviewed periodically.

NAECA mandates a maximum energy conservation or minimum efficiency level for most appliances. In a few cases, the standards also involve design requirements, such as the elimination of standing pilot lights. Table V.1 shows mandated efficiency levels for space conditioning equipment and refrigerators as well as freezers, and improvements compared to the average stock in 1985. According to NAECA standards, the largest energy savings can be achieved for refrigerators and freezers, followed by water heaters and central air conditioners. More than 90% of the energy savings are in electricity use. The standards should eliminate the need for an estimated 16 GW of new generating capacity by 2015, mostly in peak capacity. Net benefits, evaluated at a discount rate of 5%, amount to about $35 billion, on the basis of average electricity prices in constant 1985 dollars. These results crucially depend on discount rate assumptions: Using a 10% discount rate, life-cycle savings would be reduced about 30%. Before the federal standards were promulgated, the efficiency of refrigerators had improved in the United States by 77%, that of freezers by 58% and that of central air conditioners by 29% between 1972 and 1985. For water heaters, efficiency improvements have been much less pronounced, only 5% between 1972 and 1984.

The Canadian Goverment has recently announced its intention to introduce legislation which will authorise mandatory efficiency standards for residential appliances. Standard-setting in Europe is closely related to the initiatives of the Commission of the European Communities. As mentioned above, the Commission is considering an EC-wide directive on energy labelling and mandatory minimum efficiency levels for major residential appliances. There is, as yet, no common opinion in EC countries on the effectiveness of efficiency standards and their harmonisation.

Some countries have preferred voluntary agreements between manufacturers and the government to mandatory appliance standards. For example, in 1980, the electric appliance industry in Germany entered into an agreement with the Federal Ministry of Economic Affairs to lower energy consumption of appliances 3-20% from 1978 levels, by 1985. In fact, these targets were largely exceeded, with improvements of 15-30% on average. The fact that a competitor might produce a more efficient product tends to stimulate manufacturers. In

Sweden, the National Energy Administration is involved in a project to develop and market on a limited scale an energy-efficient refrigerator/freezer, partly with the help of government purchase guarantees.

Transport energy regulations include mandatory efficiency levels for cars, speed limits and mandatory inspections. Speed limits were issued in many countries in response to the oil price shocks in the 1970s and affect not only fuel consumption but also traffic safety. They are most stringent in North America. Some countries are considering further lowering speed limits for environmental reasons. Periodic inspection of the technical condition of passenger cars or trucks is mandatory in several countries, such as Austria, Germany, Sweden, the United Kingdom and the United States. Though inspections usually focus mainly on safety and emissions, they can help improve fuel efficiency if the carburettor or fuel injection system is included.

Table V.1
NAECA Standards Efficiency Levels

Appliance	Year	Efficiency Factor	Average Efficiency*	Change (%)
Central Space Heater				
Central Gas	1992	78%	73.8%	6
Oil	1992	78%	78.6%	0
Room Air Conditioner	1990	2.5 COP	2.3	12
Central Air Conditioner			8.82	13
Split System	1992	2.9 SPF	—	—
Single Package	1993	2.8 SPF	—	—
Heat Pump			2.51	16
Split System	1992	2.9 SPF	—	—
Single Package	1993	2.8 SPF	—	—
Water Heater				
Gas	1990	54%	49.4%	9
Electric	1990	88%	83.6%	5
Refrigerator/Freezer	1990	7.52 EF	6.78	11
Freezer	1990	13.82 EF	11.55	20

* Average efficiency of a typical appliance sold in 1985.
COP: Coefficient of Performance.
SPF: Seasonal Performance Factor.
EF: Efficiency Factor (cubic feet/day/kWh).
Source: Ruderman, 1990.

The United States is the only IEA country with mandatory fuel economy standards for road vehicles. Their effectiveness is the subject of much debate. The average fleet efficiency improved from 17.7 litres/100 km in 1973 to 12.8 litres/100 km in 1986. According to Greene (1990), standards appear to have been at least twice as important as market forces such as developments in energy prices or the pressure from imports of more efficient cars and competition in foreign markets. The CAFE standard is currently 8.5 litres/100 km (27.5 MPG) for new car models, and passenger cars in the fleet average about 11 litres/100 km.

As discussed in Chapter IV, one of the constraints to the penetration of fuel-efficient technology is the long lag time before major technical changes can be introduced into manufacturing and commercialised. In addition to the technical risk that the manufacturer has to take, fragmented decision making in the road transport sector might place a manufacturer at financial risk because decisions taken today to improve vehicle efficiency may fail to match consumer demand once the product reaches the market in five years' time. This could place the manufacturer at a competitive disadvantage. Voluntary or mandatory standards are one way to improve the co-ordination of the action of the numerous economic actors involved: manufacturers, service suppliers purchasing vehicles and individual consumers. The CAFE standards, though mandatory, were negotiated with major vehicle manufacturers. These standards assured each manufacturer that its competitors would provide comparable levels of fuel economy, even if future demand for fuel efficiency decreased (as in fact occurred). This reduced a major source of uncertainty for the manufacturers (Hillsman and Southworth, 1990). In addition, by requiring continual, gradual improvements in fuel efficiency to levels announced in advance, the standards reduced the technical risk of having to make major changes in vehicle design all at once in order to comply with the standards.

If appropriately set, standards and regulations can ensure a continual improvement of efficiency over the long term. But there are technical limits to the upgrading of these standards or regulations. For instance, speed limits cannot be lowered beyond a certain point. But there is still considerable room for progress by introducing standards for new domestic equipment and vehicles. There is also a need for harmonised testing procedures and standards that make it easier to compare equipment produced by different companies and in different countries. Such harmonisation would be particularly useful for cars and certain residential appliances.

(c) pricing and fiscal policies

Pricing is certainly one of the most important instruments of energy policy. If properly set, prices send the right signals to invest in supply capacity and energy efficient technology. Energy prices obviously play an essential role for initiatives to enhance efficiency, because energy efficiency investments depend on the decisions of thousands of institutions and millions of individuals. These decisions cannot be taken centrally, though they will respond to the play of market forces and in particular to the price of energy. As a result, all IEA countries have increasingly sought to get prices onto a more economic basis. There is general agreement among IEA countries that where world markets exist, consumer prices should reflect the world market price; in other cases, consumer prices should normally reflect the long-term cost of maintaining the supply of the fuel concerned (IEA, 1987).

There has been remarkable progress in the removal of controls on energy prices since the early 1980s. But for certain forms of energy in many IEA countries prices are still below the level that the pricing principles agreed by IEA Member countries would suggest. For instance, oil product prices are not fully decontrolled in all IEA countries. Because electricity and gas production and distribution are or have been franchised monopolies in most IEA countries, their prices are necessarily regulated in one way or another. The rate-of-return price regulation, for example, may prevent electricity prices reflecting the marginal costs of supply. Another problem is that world market prices are affected by short-term influences and may not reflect the long-term outlook, let alone such externalities as the environmental impact of energy production and use.

The first step governments can take to remove market distortions working against energy efficiency is therefore to allow prices to reflect the long-term cost of supply, including distribution and external costs. In most IEA countries, however, for a variety of reasons, tariffs for grid-based energy forms (particularly electricity) are not based on the long-run costs associated with supplying energy but on the average (historical) costs experienced by utilities, possibly including provisions for necessary investments. In many cases these prices understate the value of electricity. The problem is compounded by the fact that it is not clear to what degree prices really influence electricity demand. A review of the literature on this topic shows a large degree of variation in elasticity estimates, even for a given country and a given sector (Mills, 1989, and Dennerlein et al., 1987).

Governments in several Member countries have encouraged changes in tariff structures in order to reflect supply costs more closely and in many places the principles for price setting are under discussion. In Germany, for example, the government has diminished demand-related degressive tariffs for residential and commercial consumers by reducing the fixed charge and new pricing relates the demand (fixed) charge more closely to the actual load required. Similar reforms have been undertaken in Austria, where three regional utilities have started to offer residential customers tariffs that relate the capacity charge to the actual load requirements instead of to parameters that are only insignificantly correlated to load requirements (96 hour tariffs). The Cartel Commission in Switzerland recommended in 1989 that utilities establish tariff structures and levels that are more accurately aligned with the costs of supply. The recommendation was supported by the Federal Government.

Taxes and levies applied by governments also influence energy demand through market signals. It is generally agreed by IEA countries that proper weight should be given to energy policy objectives in tax policies and that energy prices should also internalise, as far as possible, certain externalities such as the environmental costs of energy production and use — the "polluter pays" principle. All IEA countries apply taxes or levies to a certain extent, primarily for fiscal reasons. For example, most countries levy value-added tax or similar excise taxes on energy end-uses, though there are variations between countries. VAT is usually refundable for commercial and industrial uses and therefore affects only residential and private transport energy demand. Tax differentials on energy products have been used mainly in the transport sector, between gasoline and diesel. Diesel prices, including taxes, are usually noticeably lower than gasoline prices in countries with an important freight transport industry.

Though higher taxes on energy products can be a source of revenue for funding measures to reduce greenhouse gas emissions, their effect on energy demand is limited by the issues discussed in sections 4.1.2 and 4.1.3. For instance, the average fuel efficiency of new cars in the United States is similar to that of new vehicles in European countries, where fuel prices are much higher (see Table III.19). Von Hippel (1987) argues that when cars reach a fuel efficiency level of about 7.8 litres/100 km at present fuel prices, the life-cycle cost of improving fuel efficiency offsets reductions in the life-cycle costs from lower fuel consumption. In addition, purchasers behave as if they used very high discount rates. As a result, they become indifferent to further improvements in fuel efficiency, even given large increases in the price of oil. Von Hippel suggests that this point of indifference may already have been reached in the automobile market and that higher fuel prices will have little effect on the fuel efficiency of new cars being purchased. The largest share of the life-cycle costs of a car is related to the purchase price, insurance and maintenance — one-time or infrequent expenditures. Fuel costs, however, are incurred regularly and frequently, and they are basically the only costs that can be controlled by the consumer once the car is bought. The individual can react to higher prices by cutting the intensity of use, resulting in reductions in the average distance driven and in related energy demand.

Primarily as result of concern about possible climate change and in recognition of the relationship between price rises and energy demand, several European countries are considering or, in a few cases, have introduced environmental energy taxes (see section 1.2). For example, Denmark a country that has already used taxes explicitly as an instrument of energy policy — plans to impose environmental taxes whose levels are related to the sulphur and carbon content of fuels, and is considering partially extending these taxes to industry and the commercial sector, which hitherto have been exempt from such taxation. Switzerland and Norway are considering environmental taxes and in Sweden such taxes were recently established. In the Netherlands, existing environmental taxes are used to finance pollution control measures and the introduction of larger, revenue-neutral taxes aimed at reducing CO_2 emissions is under consideration.

(d) other economic instruments

In addition to taxation policies, some governments have supported energy efficiency improvements through financial inducements such as grants, low-interest loans and tax deductions. Experience has shown that such activities, though effective, can be very expensive if not properly targeted. In some cases, public money has been given to consumers to do what they would have done of their own accord. This "free rider" effect resulted in a misallocation of limited public resources. In other cases, such programmes have led to unnecessary transfer of payments and cross-subsidies. The US experience with residential and industrial investment tax credits has indicated that the actual response was relatively small and that the "free rider" effect was very large. However, if programmes are carefully designed, some of these problems can be overcome. For instance, grants may be provided for energy auditing only if subsequent investments yield energy savings.

On the other hand, there are clear indications that financial support has promoted investments in energy-efficient technology and accelerated process innovation. The removal of these programmes has probably enhanced the effect of falling energy prices. Most programmes have been gradually reduced in recent years as energy prices have declined and, simultaneously, the political will to limit public spending has reduced the availability of funds. Several IEA countries still use such instruments, despite their drawbacks. Moreover, in recent years countries that had cancelled financial support programmes in the 1980s or that had never had them have introduced new subsidy or tax programmes, because of concern about the environmental impact of energy use and production.

Ireland and Austria provide tax deductions for home improvements, including retrofitting of the building shell. Norway has a grant programme that covers up to 20% of investments for energy-efficient technology in manufacturing industries and in commercial and public buildings. Luxembourg provides financial support for energy efficiency investments, such as the replacement of gas or oil burners, and for energy auditing in small companies. In the United States, mortgage financing incentives exist for improving energy efficiency in the residential sector. In a new Dutch programme, which the electric utilities have helped initiate and fund, subsidies are provided for improved home insulation and high-efficiency central heating units. It is in Italy that the largest support plan has been proposed. Between 1991 and 1993, the Government is to invest L 3 960 billion[1] in energy conservation, renewable energy sources and public transport infrastructure (including support for research on new nuclear energy systems). In 1991, the United Kingdom launched the Home Energy Efficiency Scheme, which provides grants towards the cost of loft, tank and pipe insulation, draught-proofing, and energy advice for low-income households (tenants as well as home owners). The provision for assistance to low-income households from the EEO will be about £27 million. It is expected that this project will enable some 200 000 homes to be insulated.

A recent and somewhat innovative approach has been energy efficiency performance contracting (or third-party financing). A company knowledgeable about efficient systems, processes and technology provides the financing, equipment and expertise to reduce energy use in a commercial building or an industrial plant. In return, the energy service company is paid by the building or plant manager for a share of the savings. In effect, the efficiency contractor is buying energy savings. A recent report completed for the IEA (ACE, 1988) has reviewed third-party financing activities in Member countries. It widest application was found in the United States, where energy performance contracting started in the early 1980s. In several countries in Europe, such as the United Kingdom, Switzerland and Portugal, energy service companies have since been established. Of course, energy performance contracting requires special arrangements. Companies may be linked to the supply industry, which may pose problems, and the concept may not be universally applicable, but it does underscore the almost limitless variety of market-based approaches to reducing energy consumption while maintaining economic growth and competitiveness.

(e) demand-side management

The energy supply industry, primarily those sectors that are to some extent regulated industries (electricity and gas), can play an important role in increasing the efficient use of

1. On average in 1990, L 100 = $0.083.

electricity. Electric and gas utilities usually have wide knowledge about technological possibilities to increase energy efficiency, they are familiar with the needs of their customers and they have the analytical capability to monitor demand developments. Since they are regulated industries, governments can modify their operating framework so as to provide them with incentives to support demand-side activities.

Such activities require a departure from the traditional role of utilities as generators, transmitters and distributers. Electric and gas utilities have traditionally focused on supply-side activities. So far, interest in end-use efficiency in the majority of the utilities in the IEA has been limited to influencing demand patterns to optimise load management and market share, especially the reduction of peakload because the costs entailed in serving peaks are usually not fully reflected in tariffs.

Since the late 1970s, however, utilities in North America have become increasingly involved in DSM initiatives to increase the efficiency of electricity use. DSM includes traditional end-use activities, such as peak clipping, valley filling and load shifting; it also incorporates new measures to reduce demand, such as strategic conservation and flexible load shaping. DSM is part of a broader concept of resource planning that includes both demand- and supply-side options to meet cost-effectively the consumers' needs for energy services. The concept of Least-Cost Utility Planning (LCUP) explicitly incorporates energy efficiency and load management programmes as well as energy and capacity resources. Since 1986, the US Department of Energy has managed a small LCUP programme with an annual budget of about $1 million. The programme began with a review of existing activities and needs among utilities and was subsequently expanded to fund a variety of projects at utilities or public utility commissions. The DOE served primarily as a catalyst encouraging utilities to share costs and information and transfer technologies.

In response to concerns about the environmental impact of electricity production, regulators have begun to extend the concept beyond direct economic costs to include externalities. Several state public utility commissions allow a premium to be included in the cost calculations of utilities' investments in energy efficiency. For example, in the Pacific Northwest, energy efficiency investments receive a 10% bonus in economic calculations; that is, energy efficiency resources can cost up to 10% more than supply alternatives (Goldman, 1989, and Gellings, 1990). Other such regulations include (Gellings, 1990):

- Wisconsin: requires 15% cost discount for non-combustion resources;
- Oregon: requires 10% cost premium on supply-side projects;
- New York: values emissions, land use and water quality and includes them in bid evaluations;
- Vermont: considering 15% discount for demand-side management programmes;
- Iowa: considering 10% supply-side premium;
- California: collaborative process recommends 10-25% supply-side premium;

- Washington: proposing the inclusion of environmental effects — specifically CO_2 — in LCUP process;
- Massachusetts: ruling that environmental factors be "quantified to the extent possible" for use in planning.

The motivation for utilities to undertake LCUP and DSM is not readily apparent and depends on individual circumstances. Factors that induced utilities in the United States include regulatory requirements, capacity shortages, increased fuel costs and time lags in passing these increases on to consumers, and developments in capital markets in the early 1980s, such as higher interest rates for borrowed capital (Untermark, 1989). In many utilities' service areas, public opposition to new generating units of any kind is so strong that utilities have to invest in demand reduction if they want to continue supply without financial losses. Finally, DSM improves consumer relations and can be used for marketing purposes. Furthermore, utilities generally see a financial advantage in reducing demand if the costs of such initiatives do not exceed the difference between the loss in revenue and the avoided costs of not meeting the increased demand. This is possible when the tariffs allowed by regulatory agencies or set by the utility are below long-run marginal costs. However, if tariffs are set at or above long-run marginal costs of supply, utilities have little or no financial advantage in DSM. Regulations that allow prices to reflect marginal costs, such as the price formula for the newly privatised electricity industry in the United Kingdom, can considerably reduce the need for certain DSM activities. In addition, there are many differences in the methods used to determine the rates of return or earnings of private utilities.

DSM includes technical advice, information campaigns, energy audits of buildings and industrial plants and give-away or rebate programmes for new and more efficient technology, such as high-efficiency light bulbs and refrigerators. In the residential sector, weatherisation, insulation of water systems and interruptible appliances have been tried. In the commercial/public sector, efficient lighting programmes, building shell retrofits, improvements in space conditioning equipment and heat/cool storage systems have been implemented. In the industrial sector, utilities have also offered special rates to increase the incentive for industrial customers to reduce or avoid use of electricity during peakload periods.

Clearly, the United States has the largest experience in DSM; 43 states are actively involved in such initiatives, though their intensity and range vary — 25 states are practising DSM, eleven have developed initiatives and seven are considering them. In a survey by Herppich (1989), it was found that the investments in DSM have a small share of total utility investments, only 1-2%, and expected energy savings are likely to be of the same magnitude. Gellings (1990) analysed the DSM activities of eight major US utilities. This survey shows that in recent years the utilities' DSM expenditures have considerably increased both in absolute levels as well as shares of revenue. Between 1988 and 1990, expenditures increased from $141.5 million to $288.7 million and their revenue share rose from 0.68% to 1.26%. Another survey, by CERA (1990), reveals similar developments; the share of DSM budgets in 16 utilities ranged from 0.3% to 6% of total revenue. The programmes generated energy savings of about 6 TWh and reduced peak demand by about 1.8 GW. Total budgets for these programmes were $750 million in 1990. The largest participating utility, Pacific Gas and

Electric, invested about $138 million in 1990 and its initiatives are expected to have a peak demand impact of 120 MW (in 1989 the peak load was about 18 000 MW).

DSM programmes currently under way in the United States have made it necessary to increase the exchange of information among participating utilities. In recognition of these needs, 20 utilities in the Northeast established in 1987 a non-profit group that collects and shares information on DSM costs, performance and programme design. NORDAX (Northeast Region Demand Side-Management Data Exchange) is the first regional DSM database; it contains information about 123 utility DSM programmes (Fuller, 1990). Regions that have been less involved in DSM, such as Europe, may consider launching similar initiatives or participating in such a clearinghouse, which is extremely valuable for programme transfer among utilities and across countries and regions. Better exchange of information could prevent repetition of less successful programmes and facilitate data gathering, programme evaluation and the distribution of analytical capabilities. Information exchange can also help cut the administrative costs of DSM initiatives, which can be large. A recent US study (Berry, 1989) quantified the administrative costs of programme planning, evaluation, marketing, auditing, quality control, data collection and related activities. For residential-sector programmes administrative costs are about 20% of the total costs of demand-side programmes. Commercial lighting programmes show significantly lower administrative costs, about 10-15%.

Outside the United States, Canada has the most advanced DSM activities. British Columbia Hydro will spend about C$ 330[1] million over the next 20 years in the residential, commercial and industrial sectors on initiatives such as building retrofit, energy auditing, energy management control systems and refrigerator and lighting efficiency. The company expects total savings over the next two decades of about 52.5 TWh. Ontario Hydro plans to meet 25% of its projected electricity demand growth through DSM measures costing C$ 2.5 billion.

Other IEA Member countries have launched similar initiatives. In Australia, state regulators in Victoria see DSM as one way to comply with environmental objectives, particularly to reduce electricity demand and hence greenhouse gas emissions in areas where electricity is primarily generated in coal-fired plants. In the Netherlands in 1990, energy distribution companies took the initiative to introduce a nation-wide energy efficiency and DSM programme as part of their "Environmental Action Plan". New legislation introducing competition in the Dutch electricity sector, vertically disintegrating production and distribution and merging electric and gas utilities has proved to be an incentive for an active policy of adopting DSM, energy efficiency, CHP and wind energy for distribution utilities.

The main activities developed by distribution companies include information and advice programmes; building insulation projects including partial financing (for instance through leasing arrangements); purchase of co-generation equipment with governmental support; investments in wind power (with a target installed capacity of 250 MWe by 1995); and promotion of high-efficiency light bulbs. DSM activities represent annual expenditures equivalent to $150 million and tariffs are permitted to increase by a maximum of 2% to provide the necessary funds.

1. On average in 1990, C$ 1 = $0.857

In addition to Dutch utilities, those of a number of other European countries (e.g. Denmark, Germany and Sweden) have undertaken programmes to increase the introduction of more efficient light bulbs by providing financial incentives for the customers. Mills (1991a) analysed 40 lighting efficiency programmes, which applied financial incentives, such as wholesale discounts, rebates and give-away programmes. A regional Austrian utility ran a one-year rebate programme in 1989 for the replacement of residential appliances, including refrigerators and washing machines. The rebates, deducted from the electricity bill, were granted only if the new appliances were at least 25% more efficient than the equipment replaced. The campaign significantly accelerated the stock turnover and also supported environmental objectives; for example it provided the possibility of centralised treatment of chlorofluorcarbons (CFCs) from old refrigerators.

Although participation in these programmes was significant, a rigorous evaluation would be required to analyse their impact on electricity demand in the short and long run. For example, some customers have not replaced a 60-W incandescent bulb but a 40-W lamp, others extended their intensity of use because of reduced operating costs. These effects may partially offset the impact of end-use programmes on electricity demand reductions. While generating units, whether fired by gas, oil, coal, nuclear power, hydropower, or municipal garbage, can generally be counted on to produce power once built, it is not certain that customers, once given a grant to reduce electricity consumption, do not increase their energy use elsewhere.

To assess how much DSM can contribute to reductions in electricity or gas demand requires a careful evaluation of costs, demand impact and consumer behaviour, which is often not sufficiently done. This seems particularly true for programmes that require major investments by utilities and involve subsidising consumers, such as rebate or give-away programmes. Such initiatives can induce strategic behaviour in consumers, which can have unexpected long-term implications. Participants may well anticipate the next programme and therefore postpone investments in new or efficient technologies. Such transfer of payments may not only unduly burden non-participants, but they can also lead in the long run to higher-than-expected energy demand.

Rebate or give-away programmes that substantially increase sales of appliances can also constitute a subsidy for the manufacturer. For example, Mills (1991a) has found that give-away programmes have substantially increased sales of CFLs, indicating that transfer payments have occurred. Though such payments can theoretically be an appropriate way to induce accelerated penetration of efficient appliances, their overall economic impact needs to be carefully evaluated. To make DSM an effective tool for the promotion of energy efficiency, programme evaluation is crucial to assess possible rebound effects, total programme costs and the broader economic impact, as well as consumer behaviour (Cicchetti, 1989, and Kolbe, 1990).

(f) R&D

R&D budgets in IEA countries can support energy efficiency through the development of new end-use technology and by demonstrating to industry such technology's feasibility.

From 1980 to 1988, R&D budgets for energy conservation in the IEA fluctuated considerably. They peaked in 1980 at $793.1 million (adjusted to 1989 prices) and fell in 1989 to a low of $367.1 million — less than half of the 1980 expenditure. This substantial decline is largely due to budget reductions in three of the four countries that spent the most in 1980; Japan did not reduce its budget, but the US budget fell from $434.7 million in 1980 to $149.9 million in 1988, Germany's fell from $65.4 million to $15.3 million and Sweden's from $51.1 million to $24.8 million (IEA, 1990d). Reductions in spending for energy conservation have been particularly pronounced, probably because of two major factors: the fall in energy prices in the early 1980s and a greater reliance on markets for R&D activities. Although coherent and comparable figures for R&D expenditures in the private sector are not available, it is likely that industry as well substantially reduced energy-related research activities between 1980 and 1988. Nevertheless, recent energy R&D budgets show that allocations for energy efficiency are now increasing. In the United States, for example, a 17% increase has been proposed for the 1992 budget.

R&D can be carried out on a risk-sharing basis in co-operation with the more fragmented industries such as the building industry and appliance manufacturers. Most energy-efficiency research initiatives undertaken by IEA Member countries consists of applied research to improve the efficiency of existing equipment, materials or process design. And the most important goal of such activities is to facilitate market entrance for new products through co-operation in the demonstration of a new technology. Examples include co-operation with the building and architectural industry to design and demonstrate super-efficient buildings, and funding for organisations to demonstrate new ways to use energy more efficiently.

It is a historical fact that government R&D expenditures on conservation decline at precisely those times when market mechanisms that would support the development of the technology needed for the future no longer find this research an attractive investment. When energy is relatively inexpensive, as it has been since the mid-1980s, the development of new, more energy-efficient technology appears less attractive. This is also the time, judging from budget figures for IEA Member countries, when governments pare back energy efficiency R&D efforts.

Finally, international co-operation is an important part of R&D efforts. Participation in international forums or data networks helps in transferring know-how and prevents unnecessary duplication of work and waste of public funds. IEA Member countries have often avoided repeating each others' mistakes by co-operating in the exchange of information on efficient technology and practices.

(g) the exemplary role of governments

Governments' efforts to stimulate energy efficiency in areas for which they are responsible, such as public buildings, can in principle be grouped in all the categories previously described. They can range from information campaigns to increase civil servants' energy awareness or to control temperature in public buildings, to direct financial support. However, the common nature of these activities that help reduce energy demand in the public sector — and that can stimulate similar activities in the private sector, with a multiplying effect — makes a separate discussion of them desirable. Furthermore, several countries have recently begun to emphasise the role of governments in the areas of their immediate responsibility. Such initiatives can generate success stories, show leadership and provide the basis for a start-up industry to expand into other areas of the economy. And if the investments required are made prudently with low payback times, this demonstrated success can be emulated in the private sector.

Governments have a clear responsibility to use energy efficiently in their own buildings, vehicles and establishments. This is often very difficult because government accounting systems rarely allow a government department to retain any savings arising from efficiency investments. But some have made and are continuing to make efforts in this area. A number of government-wide programmes have been launched as a means of reducing overall government expenditures. Examples are Australia's energy management programme; Austria's building and heating retrofit programme; Canada's "Save 10" programme; Switzerland's retrofit programme; and Danish efforts to increase the efficiency of electricity end-use and reduce heating demand in state-owned buildings. The UK Government has set up a ministerial committee, under the chairmanship of the Secretary of State for Energy, on which all departments are represented. Its objectives include the promotion of energy efficiency on government property and all government departments have adopted a target of a 15% reduction in energy use over a five-year period. The United States recently launched a lighting replacement programme in federal buildings. Through an investment of $13 million on new, highly efficient lighting equipment, the Government projects an accumulated saving in energy costs of $930 million over the next ten years. This high payback investment should stimulate industry to do likewise. As in the case of the US initiative, which is part of an overall response to global environmental concerns, other governments are re-examining their leadership roles in reducing energy consumption and thereby air pollution.

1.2 Review of pollution control instruments: applications and effectiveness in terms of pollution reduction and effects on energy demand

Environmental protection policy uses the same basic instruments as energy efficiency policy: information, regulation and a variety of economic instruments. A detailed review of these instruments can be found in the IEA study *Energy and the Environment: Policy Overview* (IEA, 1990c). The analysis presented here focuses on policy instruments that have been developed primarily to protect the environment and control pollution, but that have an impact on energy use and efficiency improvements. Of particular interest is such instruments' effect on decisions to carry out improved energy efficiency measures and investments, including whether emission reductions achieved through energy efficiency improvements can be fully credited in pollution abatement requirements. The environmental control instruments examined as part of this analysis are:

- emission regulations and standards applied to energy facilities;
- taxes and tax differentials related to emissions;
- pollution control investment assistance to industry, and R&D funding;
- market based instruments, such as emission trading programmes.

The choice of pollution control responses is determined by the technical options available to reduce the environmental impact of energy activities while meeting energy needs. Technical options for controlling pollution fall into two broad categories: add-on technology and clean energy technology. Add-on pollution control technology involves treatment systems, with little change in operating or production processes, and usually means end-of-line treatment. Though add-on technology is usually designed originally for new equipment and facilities, it can almost always be retrofitted in existing installations, albeit more expensively, perhaps. Clean energy technology combines more energy-efficient processes or operations with reduced pollutant production without necessarily entailing a change in the form of energy used. It is primarily designed for new equipment and facilities.

Many types of add-on technology have been and are still being developed to limit environmental impact. Major examples include three-way catalytic converters to control emissions from vehicles and flue gas desulphurisation (FGD) for stationary combustion facilities. Add-on technology suffers from a variety of technical and economic limitations. Installation represents a non-productive investment for the operator and often increases operating costs. In addition, the cost of such technology often does not change in relation to the size of the facility and can prove a large burden for smaller plants. There is also the question of the fuel economy penalty attached to the use of most add-on technology. This is largely a matter of scale and in many cases may not be a major consideration at present, but the increased CO_2 emissions due to fuel economy penalties must be taken into account when alternative pollution abatement strategies are considered.

Pollutant emission and waste production often mean a net loss of raw materials, reactants or finished products. Measures that increase the efficiency of manufacturing processes can prevent pollution as they save or recover materials. This approach is the basis of the varieties of clean technology that have been developed in a broad range of industrial and energy activities, especially in the area of coal use. For instance, clean-coal technology typically reduces emissions of SO_2 and NO_x by 70 90% and provides improvements in energy efficiency on the order of 6% compared with traditional coal combustion (IEA, 1988). Unlike most add-on technology, clean technology does not entail a fuel economy penalty and usually reduces CO_2 emissions. In fact, clean energy technology may considerably reduce the cost of pollution abatement, particularly as it usually reduces emissions of several pollutants simultaneously. Such benefits make it possible for some clean technology expenditure, like energy efficiency expenditure, to provide investment returns.

Environmental control is increasingly more stringent, systematic and comprehensive, placing more emphasis on prevention rather than cures, especially where required pollution reductions cannot be achieved by add-on technology alone. The development of multipollutant solutions acknowledges the interactive effect of pollutants at different scales and on different environmental media. Increased efforts are also being made to harmonise environmental control policy and instruments internationally because of the combined effect of concern about trade and competition and about the transboundary nature of pollution problems.

The trends described above could bring about significant changes in the energy systems of IEA Member countries. They highlight the importance of choosing approaches that are comparatively cost-effective and will achieve environmental goals as fast as possible, within the limits of energy supply and demand systems that can ensure greater energy security. The wide variety of instruments used for environmental control in Member countries makes it possible to draw lessons from experience and consider improvements that might be made to better integrate energy efficiency and pollution control. Flexibility has not necessarily been an explicit goal of environmental control measures, nor have energy efficiency improvements been specifically built into control strategies. It is increasingly being recognised that using rigid environmental instruments can rule out cost-effective control strategies, such as energy efficiency, and prevent the development of technological innovations that are ultimately the key to a lasting reduction in pollution.

As is the case for instruments to encourage energy efficiency improvements, environmental control instruments are usually designed to be mutually supportive. For instance, economic instruments are often used in parallel with regulatory tools such as emission standards to enhance the overall effectiveness of environmental control policies. They therefore form an important link between the marketplace and regulatory policy.

(a) emission regulations and standards

Regulatory instruments applied to environmental control include a broad range of measures, a number of which have a direct impact on energy use. These include fuel quality and use regulations, emission standards and prescriptive technology standards.

Fuel quality standards of various types are used in nearly all IEA Member countries. Trade-offs between the environmental performance and energy efficiency performance of fuels have been the subject of much debate, notably in the case of lead in gasoline. Legislators, refiners, automakers and consumers are increasingly aware of the advantages of improved fuels that can combine the dual goals of energy efficiency and low emissions. This approach to the search for cleaner fuels is exemplified by the promise shown by clean, high-cetane diesel fuels, which can preserve the fuel economy advantages of diesel while improving their environmental performance.

Control of fuel use has been used as a strategy to reduce air pollution or to satisfy general environmental and health concerns on a permanent or, in the case of seasonal pollution, temporary basis. In some heavily polluted areas, such as Ankara, coal use is restricted, particularly in winter. In Milan and Athens, heavy vehicle emissions have led to restrictions on the use of private cars. While these restrictions may have a temporary effect on energy demand, they do not encourage the development of more energy-efficient technologies and cannot be considered as more than stop-gap measures.

Emission standards, widely used in IEA Member countries, set a maximum allowable pollution output for various sources (transport, power plants, industry) by type of pollutant. A further distinction is made according to fuel and, often, technology. Allowance for ability to control and to pay the cost is common; less stringent standards are applied to older and smaller power plants, for instance. The most widespread use of emission standards is for new vehicles and facilities, though in many countries emission standards are being extended to existing facilities.

Emission standards are most often based on the availability of control technology, as well as cost-effectiveness. Since they are closely linked to technology, they are often referred to as technology standards, though they do not actually prescribe the use of a particular technology. "Best Available Technology" (BAT) or "Best Practicable Means" (BPM) control requirements are variations on technology standards. Usually legislated for particular groups of polluters (e.g. large combustion facilities), BAT or BPM standards can be more, or less, strict than emission standards, depending upon the interpretation of the legislative language. The most rigid form of environmental regulation is the prescriptive technology standard, which defines precisely the type of control technology or method to be applied in a particular instance. Such standards are rarely used because of their inherent lack of flexibility. They are nevertheless implicit in a number of air and water quality regulations, though they are expressed as emission limits. For instance, stringent limits for NO_x emissions from vehicles necessitate catalytic converters.

The combination of standards adopted can limit the use of certain control methods even when they are capable of achieving the required efficiency of pollution reduction. In the case of SO_2 control, for instance, there is a trade-off between removal efficiency, initial fuel sulphur content and the use of add-on technology. Where emission standards alone are specified, plant operators can use either low-sulphur coal (alone or in combination with sorbent injection), or high-sulphur coal and FGD. A percentage removal requirement limits the operator to using control or combustion systems that result in the specified removal efficiency regardless of the initial sulphur content, thus eliminating add-on technology, improved energy efficiency and clean energy technology.

The use of add-on technology has essentially been induced by regulations based on emission standards. As described above, most legislation makes some sort of reference to technology, sometimes implicitly. Though the ways emission standards are expressed vary according to country and case, widespread recourse to add-on technology has been encouraged by the way environmental legislation has been framed. The US National Energy Strategy includes actions aimed at examining federal regulatory programmes, in co-operation with the Environmental Protection Agency, to ensure that the use of waste minimisation technology is encouraged. New legislation or modification of regulations will be proposed where needed (USDOE, 1991).

Whether greater energy efficiency technology can be used to meet emission reduction requirements depends largely on the tailoring of regulations. A factory that has to make substantial emission reductions might benefit greatly from the contribution of cost-effective energy efficiency measures. If the management decides to take full advantage of the opportunities presented by end-use efficiency measures in an integrated energy/environment response to pollution regulations, it can succeed only if emission reductions resulting from energy efficiency are somehow specifically accounted for and credited in environmental control. In the case of an electric utility, LCUP could well be the best way to incorporate greater energy efficiency as an environmental response, but only as long as the environmental regulations allow for its contribution to overall emission reductions.

In many cases, however, although improved energy efficiency reduces emissions, the environmental legislation is not designed to provide full credit for emission reductions resulting from cutbacks in plant energy use. For instance, point-source emission standards, when expressed in terms of energy input or a concentration of pollutant in flue gases, may not encourage recourse to options involving improved energy efficiency. It can be particularly difficult to adjust such standards to include emission reductions from improved efficiency because estimates of savings arising from DSM programmes are often uncertain. Furthermore, the programmes may take considerable time to take full effect and there is usually no way to account for deferred environmental benefits.

The form and application of a given emission standard may also influence the rate of early retirement, life extension or construction of plants, depending on whether the same standards are applied to new, existing and refurbished facilities, and whether the standards within each of these categories are set on a case-by-case basis or are uniform. For instance, less stringent standards applicable only to existing plants can discourage construction of new plants, such as those using clean energy technology. Depending on demand (and demand management), this could result in the continued use of old, inefficient plants rather than the building of new, more efficient, cleaner plants.

Alternatively, an emission ceiling or bubble — a limit to the total volume or mass of pollutant produced over a given period of time — for individual plants, for a given company or utility, or for a geographical area, allows greater flexibility to choose clean energy technology or improved energy efficiency to reduce total emissions. If an emission ceiling encompasses all of a company's or utility's generating units (i.e. both new and existing plants), the operator benefits further by avoiding emissions via clean technology or improved energy efficiency, because the cost of building new plants is deferred.

Regulations also have a strong influence on the choice of technology and ultimately on its availability, as a direct result of how they affect the rate of stimulation of innovation and dissemination of new technology. An "average standard" — that is, one based on a technology that is applied by most firms and easily adopted by others — is often justified on economic grounds and encourages a wide dissemination of existing technology, but because it allows no choice of technology, it does little to stimulate innovation. A "model standard", however, is based on technology applied by the most advanced and innovative firms. Though it also restricts choice, at least innovative technology is disseminated and consequently technical change is encouraged. Taking the search for technical efficiency further, the "technology-forcing standard" is based on experimental technology that has not yet reached industrial exploitation. As the name implies, this again severely restricts choice but does encourage innovation, though this can backfire if unreliable technology is forced into commercialisation too soon.

Mandating the use of a given technology or group of technologies may not result in a least-cost solution. For example, depending primarily on the ease of retrofitting, the cost of installing FGD can make this anything from moderately attractive to totally non-economic. A least-cost solution is more likely to be attained if those aware of all site-specific variables are given flexibility to select the best control technology for each facility. In general, the greater the number of regulatory instruments applying to a single plant, the more restricted will be the operator's choice of approaches. The number of instruments in place varies considerably among countries.

(b) taxes and charges related to emissions

Tax differentials have most commonly been used as incentives in transport, with higher taxes on more polluting vehicles. In 1985 and 1986 car taxes were instituted in Germany, the Netherlands, Norway and Sweden to encourage the purchase of cleaner-running cars. Japan is expected to introduce a tax differential favouring the purchase of vehicles that meet new NO_x standards. Taxes are also used in many IEA countries to affect gasoline pricing, with higher rates on leaded gas. Along with a wider availability of unleaded gasoline, these taxes have been effective in boosting sales of unleaded fuel.

The application of environmental taxes in the energy sector has been widely discussed recently, particularly with reference to carbon taxes, applied to energy products according to their carbon content and the amount of CO^2 they produce during combustion. Though a number of Member countries are considering the possibility of carbon taxes to capture externalities, few have adopted them and where they do exist they are quite modest and unlikely to result in an overall decrease in energy demand. Historical elasticities indicate that the price of energy would have to rise considerably for aggregate energy consumption to stay constant over the medium to long term.

The emerging consensus is that for a tax to be effective in reducing concentrations of greenhouse gases over the long term, it would have to be ultimately very substantial, geographically widespread and applied across the spectrum of carbon-based fuels. The IEA Secretariat has, in a number of cases, analysed the possible impact that such taxes would have if applied on an OECD-wide basis. As part of a sensitivity analysis carried out on the IEA World Energy Outlook (IEA, 1991b), two cases are presented: one based on a tax of $65 per metric ton of carbon, and one based on $130 per ton of carbon. These taxes are equivalent, respectively, to $8 and $16 per barrel of oil, $45 and $90 per metric ton of coal, and $1 and $2 per MBtu ($1.06 to $2.11 per GJ) of natural gas. In both cases it has been assumed that the tax would take effect immediately. The analysis also makes the conventional and neutral assumption that all the revenues from such a tax would be fully recycled within each economy.

Of course, before any substantial and OECD-wide carbon tax could actually be implemented, many practical, economic and institutional obstacles would first have to be overcome. In any case, the use of a carbon tax in this sensitivity analysis is for purposes of illustration only; it should not be interpreted as implying that the IEA is either in favour or not in favour of countries levying such a charge.

Table V.2 summarises the effects that the assumed taxes would have on OECD primary energy consumption and energy-related CO^2 emissions. Since the tax increases the final price of a wide spectrum of fuels, it affects total primary energy consumption directly. In both cases examined here, around 70% of the projected reduction in CO^2 emissions would result from lower overall energy consumption rather than from changes in the fuel mix. On the other hand, since the tax is applied differentially according to carbon content (among the fossil fuels, coal emits the most carbon per unit of net useful energy, while natural gas emits the least), it comes as no surprise that there would be a shift in consumption, away from coal and oil and towards natural gas, as the latter bears a lower (though still substantial) carbon tax. Indeed, the analysis suggests that the impact on natural gas consumption would be very small, and in fact slightly positive. This substitution effect accounts for the remaining 30% reduction in CO_2 emissions resulting from the tax.

Table V.2

Impact of Two Hypothetical OECD-wide Carbon Taxes on OECD Energy Consumption and Emissions in 2005

(per cent deviations from reference-case levels)

	Tax Per MetricTon of Carbon	
	$65	$130
Coal and other solid fuels	-17.2	-26.1
Petroleum	-3.0	-7.0
Natural gas	1.0	0.1
Total Primary Energy Supply (Consumption)	-5.2	-9.1
CO_2 Emissions	-7.5	-12.7

Under the $65/ton tax scenario, emissions of carbon in 2005 would be about 8% lower than they would be under the reference (gradually-rising-oil-price) scenario. Under the $130/ton tax scenario the deviation from the reference case would be about 13%. However, even the $130/ton tax would leave total OECD emissions of CO_2 in 2005 about 7% higher than current emission levels.

(c) financial support

As in the case of energy efficiency policy, financial assistance for environmental control is usually used, and indeed is most effective, as a complement to regulatory and other measures rather than a substitute for them. *Pollution control investment assistance* to industry is usually intended to aid in the transitional period when stricter emission standards go into effect. Subsidies or financial assistance programmes are used in most IEA countries, mainly for equipment purchases, though some countries also subsidise personnel training and audits. The main types of subsidies are grants, soft loans (i.e. below market interest rate) and tax allowances. A number of IEA Member countries have decided that changes in production processes, including energy efficiency improvements, and clean energy technology are eligible for financial support for pollution control.

Most Member countries provide *financial support for R&D* of pollution abatement technology in a variety of ways. Sweden provides significant support for the development of clean energy technology, using revenue from pollution charges. The Netherlands and the

United States provide direct assistance for demonstration of clean technology. The United States sponsors the Clean Coal Technology Program, in which government funding is matched by industry for combustion control projects that have potentially high environmental performance. Canada provides financial assistance on a cost-sharing basis for private-sector technology development.

Subsidies have in some cases played an important part in the development and use of add-on technology. A survey conducted in OECD countries (OECD, 1989) shows that a broad range of grants, soft loans and tax allowances are specifically designed to promote traditional add-on technology. The study notes evidence of a shift from support for end-of-line technology towards more emphasis on development and use of cleaner, more efficient technology. In fact, some indications exist that financial assistance for traditional add-on technology that is used to comply with regulations will be considerably diminished, if not terminated, in the medium term. The ability of clean-coal technology to reduce CO_2 emissions along with emissions of traditionally controlled pollutants is likely to prove a bonus in the support it receives. In the United States, the DOE's R&D matching grant programme gives extra credit to innovative clean-coal technology projects that also reduce CO_2 emissions.

For any form of economic incentive to become a real stimulus for innovation, a delicate balance must be found between the technological preferences imposed or suggested by the authorities and the freedom of innovation that is allowed. Like technology-based regulations, financial aid can greatly affect the technological response capabilities of industry and the dissemination of innovations. For financial support programmes to be flexible enough to encourage development of more energy-efficient production processes or reorganisation of an energy activity to minimise environmental impact, they must be specifically designed for this purpose.

Financial aid is also provided to accelerate environmental investments. A case study of financial aid in Germany shows that while certain programmes have produced considerable acceleration, there is evidence that operators apply for subsidies only when regulatory action forces them to take environmental measures. An analysis by the State Industrial Inspectorate for North Rhine-Westphalia shows that 20-40% of emission control measures taken by industry were "economically justifiable" without financial aid, rising to 50-70% with financial aid. The benefits that such programmes can provide by facilitating early compliance is debatable and their environmental effectiveness is limited. The "free rider effect" experienced in many energy efficiency aid programmes is also felt in some pollution control programmes.

Government financial support for equipment purchases is increasingly constrained in countries that are part of free trade areas such as the EC. Under the Treaty of Rome's state aid rules, financial support for such programmes in EC Member countries must be approved by the European Commission. One such programme proposed in western Germany recently included a DM 550 subsidy to buyers of cars with diesel engines that meet a particulate emission norm of 0.08 gr/km, which is stricter than the existing US and EC levels.

(d) market-based instruments, such as emission trading programmes

Markets can be created where actors might buy or sell "rights" for actual or potential pollution. The so-called market-based economic instruments include a variety of policy instruments that use the power of the marketplace to achieve environmental goals. Tradable permits (emission trading programmes) have been specifically developed to increase the cost-effectiveness of environmental control. Environmental goals are pursued by creating conditions (markets) where economic actions are developed and the actual application is left to the polluters. This means the emission reduction benefits of improving energy efficiency can be fully credited. *Emission trading is* an alternative to, and in many ways a substitute for, pollution charges. Under this approach, the same type of emission limits exist as under normal pollution control programmes, but a net account of performance is kept. If a polluter emits less pollution than the limit, the firm can sell or trade the differences to another firm, which thus gains the right to release more than its initial limit. Using various approaches, these trades can take place within a plant, within a firm or among firms.

The United States is the cradle of emission trading policy and the vast majority of such programmes are found there. "Bubbles", "offsets", "netting" and "banking" of emissions have emerged in reaction to regulations that are perceived as too rigid in some respects. As US air pollution control policy is based on achieving of ambient air quality standards by applying emission standards that vary by type of industry or source, emission trading has been used to provide some flexibility in an otherwise rigid system. It has also been applied in a more limited fashion in Germany for renovated facilities or to allow for the licensing of a new facility in a non-attainment area if reductions are made elsewhere in the same area. Though this is a relatively recent approach, there is enough experience to examine its advantages and limitations.

The main feature of emissions trading is a partial shift of decisions about environmental control from public authorities to plant operators. Thus the flexibility allowed by emission trading implies greater responsibility for industry. Though emission trading is often presented as an alternative to direct regulation, this is hardly conceivable in practice. On the contrary, the basis of emission trading is regulation, as the first step is to set an environmental quality standard for the area concerned. It is the fixed total of allowable emissions that causes artificial scarcity, leading to prices above zero where demand for and supply of pollution rights meet.

In its subsequent stages, however, the introduction of emission trading does not necessarily reduce the involvement of public authorities. Approval of abatement technology for individual sources is replaced by approval of emissions transactions. The level of the environmental quality standard should be balanced to ensure sufficient flexibility (i.e. it should not be too constraining) and effectiveness (i.e. it should not be too lax). An often-stated problem is the lack of precise emission inventories, making reliable assessments of baselines and achieved reductions difficult. It is sometimes argued that the achievement of better, or at least stable, air quality is too uncertain under market-based instruments, since authorities lose control over the application of control technology.

Further development of emission trading rests largely on the related issues of implementation strategies and environmental effectiveness. In the United States, the long preparation period for emission trading policies, and policy amendments that are still pending, indicate that this approach means a substantial workload for authorities. In general, administrative costs of setting up individual emission trading cases have been high. But it is expected that, as the practice grows, much technical knowledge will be transferred from authorities to operators, since firms themselves search for efficient, effective abatement technology. This would ultimately ease the administrative burden, at least in sectors such as industry and electricity generation where experience in emission trading is greatest. Recent proposals in the United States as part of the Clean Air Act Amendments have raised the possibility of using emission trading for vehicle emissions.

Broader applications of market-based instruments are still being explored and a variety of ideas are proposed, particularly for those environmental concerns, such as CO_2 emissions, for which no control technology is currently economically feasible. As described earlier, there is scope with such instruments for integrating non energy environmental approaches, such as reforestation, using the concept of "emission compensation", similar to emission trading, but on a global scale or in a "global bubble", although the substantially greater difficulties involved in international implementation remain unsolved. Nevertheless, these instruments and their application deserve further study and development as they seem to offer opportunities to achieve balanced, integrated responses for some of the most intractable environmental problems.

2. ASSESSMENT OF EFFECTS ON DEMAND AND EMISSION REDUCTION, AND OTHER EFFECTS

This section assesses the effectiveness of energy efficiency policies in terms of:

- the efficiency gain and emission reduction which is likely to be achieved;
- the barriers that can be overcome by the application of these policies;
- the costs involved, including governmental costs.

The degree to which policies complement and are compatible with broader economic goals and policies is evaluated. An assessment of the secondary impacts of energy efficiency policies and measures (macroeconomic consequences and energy security aspects) concludes the section.

2.1 Effectiveness of energy efficiency policies in reducing emissions

As shown in Chapter III, the relationship between historical trends in energy demand and in energy intensity is not straightforward and the relative weight of the factors involved in translating an improvement in energy efficiency into energy demand and CO_2 emission levels is difficult to establish. The analysis below first examines how the evolution of energy efficiency, as measured by energy intensity indicators, has affected CO_2 emissions. The possible effect on demand and CO_2 levels of the energy efficiency potential identified for each sector in Chapter IV will then be examined. Finally, the policy measures that would be necessary to achieve various levels of market potential and the resultant energy demand and CO_2 emissions reductions are discussed essentially in terms of costs for both the public and private sectors.

(a) efficiency gains and emission reductions: historical trends

Figure V.1 compares the evolution of TPER, CO_2 emissions, energy intensity and the share of carbon fuels in TPER from 1973 to 1988. It shows that levels of CO_2 emissions have followed the evolution of TPER, despite considerable reductions in the share of carbon fuels in the IEA since the first oil shock. Nevertheless, changes in the fuel mix and improvements in energy intensity have helped to flatten the CO_2 emission curve.

Changes in the fuel pattern (shown in Figure III.1) over the last 15 years have caused the share of carbon fuels to fall nearly 7%. Without these changes, actual emissions in 1988 would have been three percentage points higher. In other words, fuel substitution contributed to the fact that CO_2 emissions grew only 7% instead of 10% between 1973 and 1988. Historical reductions in energy intensity have also substantially affected carbon emissions in the IEA. Without the 25% decline in energy intensity since 1973, IEA countries would have emitted about 19 percentage points more CO_2 in 1988 than was in fact the case. Changes in the fuel mix and energy intensity of major end use sectors have also had a substantial, though not always positive, effect on CO_2 emissions.

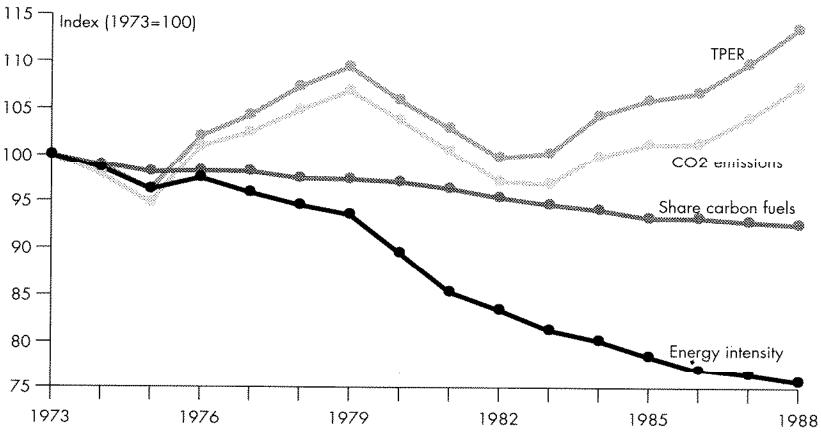
In the residential sector, if the fuel pattern of 1980 had remained unchanged until 1988, CO_2 emissions would have been about 4% below their actual 1988 values. On the other hand, if energy demand per floor space had not decreased, the emissions would have been 12% higher in 1988. In the service sector, changes in the fuel mix and in energy intensity have also had contradictory effects. If the fuel pattern of 1980 had remained unchanged, CO_2 emissions would have been 8% lower than they actually were in 1988. In other words, without changes in the demand pattern, CO_2 emissions would have been only 1% higher in 1988 than in 1980, instead of 10%, the actual increase in CO_2 emissions from 1980 to 1988. But if energy demand per unit of value added had not decreased, emissions would have exceeded actual 1988 levels by about 13%.

In industry, changes in the fuel mix have also tended to increase carbon emissions, though this has been more than compensated by the effect of the fall in industrial energy intensity. As in the case of the residential and commercial sectors, most of the fall in oil and coal use has been compensated by an increase in the use of electricity in industry. From an end-use perspective, and averaged over all IEA countries, electricity, on the basis of delivered energy, emits higher levels of carbon than does oil, so this shift has caused more carbon to be emitted per toe than historically has been the case. In 1973, IEA industry accounted for 980.3 Mt carbon while using 953.52 Mtoe. In 1988, while carbon emissions had declined to 895.8 Mt carbon, energy use had only declined to 894.75 Mtoe (i.e. by less than 1%).

Improved energy efficiency has made a significant difference in the levels of carbon emissions. While industry output was increasing 39%, carbon emissions declined 8.6%. Without these fuel shifts and at the efficiency level that prevailed in 1973, IEA industry would have emitted 1.38 billion metric tons of carbon, an additional 487 Mt, or 54.4% more.

Figure V.1

Trends in IEA Energy Use and CO_2 Emissions (1971-1988)



In the transport sector, without the improvement of the average efficiency of vehicles on the road between 1980 and 1988, CO_2 emissions would have been about 8% higher in 1988 than they actually were. Nevertheless, this gain was more than compensated by the increase in vehicle-kilometres, which reached 39% for passenger cars, 22% for goods vehicles and nearly 9% for buses. The effect of shifts towards more powerful and heavier vehicles cannot be determined on an IEA-wide basis because of lack of data. These shifts affect the fuel consumption of the new car fleet and extend to the average fleet over the ten years during which the stock is renewed. Taking the case of western Germany examined in Chapter III, it was estimated that preference for more powerful cars has reduced the average efficiency of new cars by about 7.8% between 1980 and 1988. Total road passenger traffic for 1988 was 376.5 billion vehicle-kilometres with average vehicle fuel efficiency of 10.7 litres/100 km and total consumption of 32 Mtoe (for both diesel and gasoline passenger cars). A 1 litre/100 km improvement in average fuel efficiency would therefore result in a saving of about 3.2 Mtoe per year, or a reduction in CO_2 emissions of 2.8 Mt carbon (western Germany's total carbon emissions in 1988 are estimated at 195.86 Mt carbon).

(b) the effect of improved energy efficiency on energy demand levels

The translation of gains in energy efficiency into energy demand reductions is usually the aim of most studies of future energy efficiency potential. The reference case is usually a "frozen efficiency" scenario, where future energy consumption levels can be assessed by assuming that all new equipment purchased after 1988 is as efficient as the average equipment purchased in 1988. This freezes technology at the 1988 level but allows the stock to improve over time as retirements and growth of output require new equipment purchases. The translation of purely technologically defined energy efficiency potential into energy consumption levels may assume that 100% market penetration overnight. More realistic assessments of the impact of technical improvements take into account stock replacement rates and a staged introduction of technological innovations: The most energy-efficient commercially available technology is added to the stock of equipment every time additional capacity is needed or old equipment is replaced, and advanced technology is purchased when it appears.

It is more difficult to generalise about the manner in which estimates of energy efficiency that include economic and market considerations are translated into energy demand in the studies surveyed. Because of the enormous amount of detailed information on present and future economic and energy conditions that would be necessary to fully quantify the effect of potential energy savings on energy demand, simplifying assumptions about consumer and market behaviour abound. A major pitfall is that efficiency is often measured in conditions that do not correspond to the equipment's real operating conditions. When such efficiency measures are extrapolated to a whole end-use, their effect on energy demand can be overestimated. This problem was discussed in Chapter III, when it was pointed out that the fuel economy of new cars measured by standard tests could be well above that observed in real driving conditions. In addition, evaluations of cost-effective potential may overestimate the savings that will be achieved even if the market functions perfectly. Financial savings due to improved energy efficiency increase disposable income, which can then be devoted to energy consuming activities. This issue is examined below.

Estimating the effect that energy efficiency improvements may have on levels of energy demand is complicated by the fact that more efficient use lowers the apparent cost of energy: In some cases, this may result in increased energy use, either because lower production costs make it possible to develop new markets and products, or because consumers react by spending more of their disposable income on activities involving energy use. While this phenomenon can produce considerable social, industrial and economic benefits, it has a negative effect on the energy security and environmental benefits that can be expected from energy efficiency efforts. In addition, its occurrence and scale are usually difficult to predict or assess.

In some cases, there is obviously a risk that this effect might be at work, though it is difficult to quantify precisely, because the feedback effect of energy savings depends on the choices of individual consumers and their reactions. Manufacturers of CFLs have been known to argue that the lower running cost of these light bulbs not only decreases lighting costs but also makes it possible to leave the lights on longer — for instance, when the home is unoccupied, to discourage burglars. There is a distinct possibility that users may even adopt such behaviour without the manufacturers' encouragement, because CFLs cost so much less to run than incandescent bulbs.

A number of recent studies have attempted to document the effect of energy savings on energy expenditure by car owners. A long-run increase in the fuel economy of passenger cars reduces the cost per km of travel, as shown in Figure V.2. The cost data in this figure use as a basis the calculations for passenger car operating costs in the United States in 1988, with gasoline costing $1.08 per gallon or 28.8 cents per litre (labelled Fuel costs 2 in

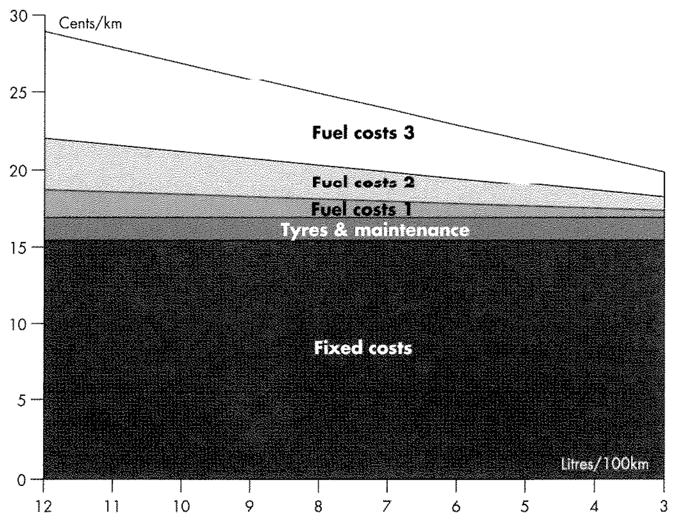
Figure V.2). The average fleet efficiency was 10.8 litres/100 km, which gives an average fuel cost of 3.11 cents/km, representing 15.6% of total operating costs. Fuel costs 1 represents half of Fuel costs 2 (14.4 cents/litre) and Fuel costs 3 is twice Fuel costs 2 (57.6 cents/litre). As efficiency improves, the share of fuel costs in total operating costs decreases, even if it is assumed that these efficiency improvements can be carried out at no extra cost. If fuel costs doubled from the 1988 US figure, and if efficiency doubled to 5.4 litres/100 km, fuel costs would still represent the same small share of total operating costs. This share and the incentive it could constitute are likely to be further reduced when account is taken of the fact that in reality, fuel economy improvements are likely to have a cost, for instance on the purchase price of the vehicle. According to Greene (1989), the reduction in the cost per km of travel due to efficiency improvements may ultimately reinstate as much as half of the initial reduction in vehicle use from higher fuel costs.

It is often argued (Brookes, 1990, and Greenhalgh, 1990) that improvements in energy efficiency that reduce energy costs will systematically result in an increase in energy use, rather than a decrease. But there are two major reasons, put forward by Grubb (1990), that this effect may not be systematic or even significant.

The first is that in this argument it is predicated on the assumption that circumstances have not changed since 1973, when in fact they have. There is reason to doubt that energy prices will ever again go through the prolonged decline experienced in the century leading up to the first oil shock. There is evidence that some household and industry uses — space conditioning, refrigeration, etc. — may have reached saturation in many developed countries. Finally, there is some evidence that fundamental shifts have occurred in the need within developed countries for basic industrial materials (Williams and Larson, 1987). So arguing that a rebound in energy use will occur after efficiency improvements based on historic evidence ignores the important changes that have occurred.

Figure V.2

Fuel Costs According to Fuel Price and Vehicle Efficiency



The second objection is that the argument confuses the role of naturally occurring efficiency improvements with deliberate attempts to increase energy efficiency when price and availability are not constraints. A rebound in energy use after an efficiency improvement may be expected where energy costs are constraining a given economic activity. This rebound may not be significant when energy price is a minor factor in determining activity levels; moreover, the empirical evidence does not support the proposition that a significant rebound effect exists.

(c) efficiency gains and emission reductions: future trends and costs

In order to stabilise atmospheric concentrations of CO_2 at current levels, it is estimated that anthropogenic emissions would have to be reduced 50-80% (EPA, 1989). According to the IEA's regular survey of actions in Member countries to deal with the issue of climate change, 19 countries have set targets, albeit preliminary ones, for limiting CO_2 emissions, or have agreed to the EC target. The targets range from stabilisation in 1995 to a 25% reduction in 2005, compared to 1987/90 levels. Where studies have been completed of the measures necessary to reach such targets, it is generally recognised that improved energy efficiency should play a large part.

The analysis of historical trends in CO_2 emissions reveals that, from an end-use perspective, energy intensity improvements in all end-use sectors have played a major role in limiting the growth of CO_2 emissions in IEA countries over the last decade, in some cases more than compensating for the detrimental effect that changes in the fuel mix of the industrial and buildings sectors have had on emission levels. This section examines how further improvements in energy efficiency may affect levels of CO_2 emissions in the next ten to 20 years. The analysis is based on a survey of the existing literature, though it is restricted to studies that also examine the policy measures necessary and calculate the costs of the CO_2 reductions. This approach is justified by the conclusion reached at the end of Chapter IV, that a large part of the significant potential for technical efficiency improvements is not being taken up by the market. Therefore, market conditions must change markedly for even part of this potential to be realised. But such changes carry a cost for energy consumers, equipment manufacturers and governments (i.e. taxpayers). The magnitude and distribution of these costs depend on the scale and nature of the policy measures taken.

This approach considerably reduces the range of studies available, because while there are many forecasting exercises that translate efficiency improvements into energy demand and future levels of CO_2 emissions, most are designed only to broadly explore possible scenarios, and relatively few attempt to quantify the overall costs involved. In some cases, though costs are given, they tend to be underestimated because they do not include the cost of the policy measures involved. This is the case, for instance, of analyses that include estimates of energy efficiency that are judged to be "cost-effective" without reference to private economics, and the costs of implementing these energy efficiency investments are then hidden in the analysis (see Chapter IV, section 1.1). It is also notoriously difficult to assess the full cost of policy measures, including governmental costs such as administrative costs, and indirect costs such as those borne by equipment manufacturers.

The studies examined below provide an order of magnitude of the energy efficiency improvements and demand levels needed to achieve certain limitations of CO_2 emissions in IEA countries. They also provide cost data on the investments necessary. Most explore the policy measures necessary, though the focus in most recent studies is on energy taxes, particularly carbon taxes, rather than other policy instruments. Sectoral effects, explored in the case of the US road transport sector and the residential and commercial sectors in western Germany and Denmark, are examined first.

(i) sectoral effects

In the United States, the growth for vehicle miles travelled (VMT) projected by the Federal Highway Administration (1988) is about 2% annually, which yields a near doubling of VMT by 2020. Thus a policy to double vehicle MPG for the gasoline-fuelled fleet during the next 30 years would reduce growth in greenhouse gas emissions but would not reduce emissions. In the short term, some improvement is likely because the average new light vehicle is about 30% more fuel efficient than the average vehicle in use, and heavy vehicles are about 15-20% more efficient (though because fuel economy measured in standard tests is lower than in real driving conditions, only part of this improvement can be translated into actual consumption). Vehicle replacement will cause some improvement in average fleet efficiency even without a change in policy. DRI (1990) examined for the US Environmental Protection Agency the magnitude of improvements in automobile fuel economy that would be necessary to limit CO_2 emissions from the transport sector over the next ten years, compared to a base case assuming that new car fuel economy would improve anyway from the present 28.6 MPG (8.2 litres/100 km) to about 30 MPG (7.9 litres/100 km). To hold CO_2 emissions constant at 1989 levels, new car fuel economy would need to be 32.4 MPG (7.3 litres/100 km). If CO_2 emissions were to decrease 20% from 1989 levels, the fuel economy of new cars would have to be 40.7 MPG (5.8 litres/100 km). The analysis carried out in Chapter IV concluded that the technical potential for cars in North America at the turn of the century is 20% (about 6.5 litres/100 km) without changes in the attributes of the vehicle and could be as much as 40% (about 5 litres/100 km) if such changes are included.

The fuel economy improvements described above will not take place without policy measures and changes in the market. The magnitude and cost of two possible measures (a fuel tax or a registration tax) was also examined by DRI and are summarised in Table V.3. In aggregate, the additional fuel tax needed to stabilise CO2 emissions from the road transport sector would cost drivers about $20-25 billion per year over the period of policy implementation, 1992-2000. If the tax was revenue neutral, GDP would decline roughly 0.4% from the base case in 2000 (which assumes GDP annual growth of 2.3%). If the tax was retained by the government, it would cost society as a whole 0.5% of GDP. Alternatively, if a vehicle registration tax was chosen to reach the 32.4 MPG fuel economy target, new car buyers would pay about $15 billion annually. Relative to the base case, there would be about 65 million fewer metric tons of carbon emitted by 2000, at costs totalling $250-275 per metric ton. In the case of a 20% reduction in CO_2 emissions, the additional fuel tax would cost drivers about $125-130 billion per year and the registration would cost buyers $50 billion per year. A revenue neutral tax would cause GDP to decline about 1.7% from the base case in 2000, while a tax retained by the government would cost society about 2% of GDP.

Table V.3
Comparison of US New Car Fuel Economy Levels

	MPG	L/100 km	fuel tax	registration tax
1988 efficiency	28.6	8.2	9 cts/G	$50/car
2000 efficiency, base case	30.0	7.9	20 cts/G	$50/car
2000 efficiency, CO_2 cap	32.4	7.3	55-65 cts/G	$1 000/car
2000 efficiency, 20% CO_2 reduction	40.7	5.8	$2.10/G	$3 000/car
2000 efficiency, technical potential (no attribute changes)	36.1	6.5	-	-
2000 efficiency, technical potential (including attribute changes)	47.0	5.0	-	-

Another policy option would be to introduce mandatory fuel standards of 32.4 MPG for a CO_2 cap or 40.7 MPG for a 20% reduction. The cost of such a measure has not been evaluated, though it can be safely assumed that substantial costs would be borne by both car manufacturers and consumers. In the case of consumers, it is likely, in view of the cost figures presented in Chapter IV, that the marginal price of vehicles that meet fuel economy standards would be at least as high as the registration taxes discussed above, which would also be paid once at the time of purchase.

The lower range of these cost figures is of the same order of magnitude as estimates produced for the cost of meeting emission standards using add-on pollution control equipment and less polluting engines. Most estimates report costs of about $800 (give or take $200) for gasoline-powered vehicles meeting current US standards (OECD, 1987). Average costs for vehicles meeting proposed EC standards are generally several hundred dollars lower, though the data are far more variable: For instance, British estimates of costs of meeting EC standards range from £300 to £800 when account is taken of the engine modifications necessary to enable a catalytic converter to be fitted. A contributing factor here is that the proposed European standards vary with automobile engine size. It appears also that all incremental costs are ascribed to emission control and no portion to increased fuel consumption or other performance changes.

A broader sectoral analysis was published in 1990 by the German Inquiry Commission, which was asked by the Parliament to assess the scientific uncertainties related to climate change and to examine different strategies to limit climate change. Four scenarios were examined:

- Moderate: continuation of current energy policy and moderate increases in energy prices;
- Energy Efficiency: removal of barriers to energy efficiency and significant increase in energy prices;
- Removal of Barriers: removal of barriers and moderate changes in energy prices;
- Energy Policy: removal of barriers, prices based on long-run marginal costs and internalisation of externalities.

Annual GDP growth of 2.5% is assumed between 1987 and 1995, and 2.3% thereafter, up to 2005. Between 1987 and 2005, the population of western Germany is expected to decline 2.1%, the number of households is assumed to decline by less than 1% and floor space is expected to increase 11%. As a result, the number of persons per household is expected to decrease 1.4% and living area per person should rise almost 14%. Table V.4 summarises the results for the residential and commercial sector in terms of final energy demand and investments and shows the marginal investments required and the costs of conserved energy (marginal costs for energy efficiency). In some instances, marginal costs exceed supply costs, particularly for new buildings and for measures focusing on electricity use in the commercial sector.

The Danish Ministry of Energy presented in April 1990 its "Energy 2000: A Plan of Action for Sustainable Development", which defines priorities in energy and environmental policy, in line with Denmark's intention to reduce CO_2 emissions 20% by 2005 compared with 1988 levels (the longer-term target is 50% by 2030), and to cut emissions of SO_2 by 60% and NO_x 50%. The plan is based on a comprehensive evaluation of different strategies to achieve these objectives, as well as a reduction in TPER of almost 15% in 2005 compared with the 1988 level.

Policy measures include, in addition to supply-side options, introducing environmental taxes, strengthening building codes for new buildings, tightening inspection guidelines for buildings and possibly introducing efficiency labelling and standards for certain electric household appliances. It is estimated that the energy action programme will not entail any additional economic costs and, compared to a business-as-usual scenario, can generate economic benefits, such as an improved trade balance and increased employment. Foreign exchange expenditure would decline by about DKr 2.4 billion and employment would increase by about 2 600 man-years. Additional investments in the energy sector of about DKr 1.8 billion a year up to 2005 would be compensated by a decline in fuel and operational costs. Table V.5 depicts the estimated costs and contributions of different measures to reduce CO_2 emissions for 2030.

Studies of the broad macroeconomic effects of energy efficiency improvements and of the policy measures and costs necessary to support them are sometimes based on detailed sectoral analysis of the type presented in the previous section, where a clear distinction is drawn between efficiency improvements and demand reductions. In other cases, the relationship between efficiency improvements, demand reductions and associated policy measures, such as carbon taxes, is simplified. For instance, a basic percentage improvement in energy efficiency is assumed to be entirely translated into energy demand reductions and the impact of price increases is treated in a straightforward manner. The large number of differing assumptions used in these macroeconomic studies cannot be covered fully, though information has been extracted to provide orders of magnitude of the macroeconomic impact expected from various levels of efficiency improvements and policy measures.

(ii) macroeconomic effects

The analysis of the strategy for energy conservation prepared as part of the intensified Dutch National Environmental Policy Plan (Ministry of Economic Affairs, 1990) examines the policy cost and macroeconomic impact of stabilising CO_2 emissions at present levels by

Table V.4

Energy Scenarios for Western Germany

	PJ (1987)	Moderate	Energy Efficiency	Removal of Barriers	Energy Policy
			(per cent reductions from 1987)		
Impact on Final Energy Consumption					
Residential					
Space Heating	1 596	-18	-44	-29	-38
Electricity	250	-17	-13	-17	-13
Warm Water	189	-24	14	-24	-24
Total Residential	2 035	-18	-35	-27	-34
Commercial	1 225	4	-19	-7	-13
TFC	7 663	7	-15	-5	-11
Impact on Emissions[1] (1987=100)					
CO_2	100	104	86	—	—
Methane	100	95	81	—	—
NO_x	100	40	29	—	—
VOC	100	38	25	—	—
Marginal Investments up to 2005 (billion DM)					
Private Households					
Heating Systems	—	—	15	3	10
Insulation (Existing Buildings)	—	—	94	50	68
New Buildings	—	—	108	27	85
Total Households	—	—	217	82	163
Commercial					
Fuel	—	—	7	2.5	4.2
Electricity	—	—	17	6.0	10.7
Electric Appliances	—	—	3	3	3
Costs of Conserved Energy (0.01 DM/kWh, 5.4% real discount rate)					
Private Households					
Heating Systems	—	—	6.0	3.5	4.5
Insulation (Existing Buildings)	—	—	7.5	5.2	6.0
New Buildings	—	—	17.0	9.3	15.0
Commercial					
Fuels	—	—	4.0	3.0	3.4
Electricity	—	—	26.0	19.0	22.0
Electric Appliances	—	—	3.2	3.2	3.2

1. Impact of most effective scenario (energy efficiency) and least effective scenario (moderate).

Source: Inquiry Commission, 1990

1994/95, which would mean improving the energy efficiency of the Dutch economy by just over 2% per year. An average improvement rate of 1% is already forecast for the 1990s, so

Table V.5

Average Costs of Reducing Denmark's CO_2 Emissions in 2030

Measure	Costs DKr 0.01/kg CO_2	Potential % of Reduction
Heat conservation in existing buildings	85	11
Heat conservation in new buildings	33	2
Electricity savings in dwellings and service	-66	12
Savings in production	-38	12
Increased CHP — natural gas	-55	13
More efficient electricity production	15	29
Maximising connection to natural gas	-43	4
Increased CHP — biomass	-17	19
Renewable energy sources	5	26

N.B.: These measures are interdependent and therefore should not be added up.
Source: Ministry of Energy, 1990.

the further 1% improvement will have to be supported by additional policy measures. About Gld 1 billion[1] of public money would be needed to induce the additional Gld 3.2 billion worth of energy conservation investments necessary to achieve this aim, though there is considerable uncertainty about the multiplier effect of public funds since, despite their profitability, such investments have not been made in the past. The analysis points out that, all in all, the effectiveness of the policy package of subsidies, regulations and action by public utilities is therefore tentative, but that greater efforts to accelerate energy efficiency improvements are nevertheless essential. Assuming that no equivalent policy measures are taken outside the Netherlands, the effects of these policy measures are positive for production and employment, though in the short term the expenditure effect of investments dominates the picture. It is estimated that in the longer term no negative effects arise because, on balance, the costs of the investments in energy conservation are smaller than their benefits, even at today's energy prices.

A recent study by Nordhaus (1990) estimates the cost of abatement of greenhouse gases through the reduction of CFC and CO_2 emissions and forestry options. Nordhaus argues that the costs of CFC reduction are quite small; most of the reduction can be accomplished for less than $5 per metric ton of CO_2 equivalent. The marginal cost of CO_2 reduction is estimated by reference to a set of models, such as the Edmonds-Reilly model, the Nordhaus-Yohe model and the Manne-Richels model. By averaging the results from these models, Nordhaus concludes that a modest reduction of 10% of CO_2 can be obtained for a

1. On average in 1990, Gld = $0.549

marginal cost of around \$20 per metric ton of CO_2. It would require a \$100 per ton tax on CO_2 to achieve a 40% reduction in emissions. When the costs of CFC, CO_2 and forestry options are combined, Nordhaus finds that a tax of \$10 per metric ton of CO_2 equivalent would reduce emissions about 15%, but beyond this the costs rise sharply. The long-run marginal costs are estimated to be \$38 per metric ton of CO_2 for a 25% reduction and \$119 for a 50% reduction, based on today's economy. These translate into \$3 billion for a 14% reduction, \$27 billion for a 25% reduction and \$201 billion for a 50% reduction on a global scale. Industry's share of these costs would be 30-45%.

It is instructive to compare the cost figures produced in the Nordhaus study with estimates of the cost of current environmental expenditure. According to the US Department of Commerce, \$78 billion was spent on all forms of environmental protection in 1986, amounting to just under 2% of GNP; about two-thirds was spent by industry (Moore *et al.*, 1989). A number of studies have attempted to measure the effect of pollution control on productivity and economic growth, with widely differing results. For instance, Denison (1985) finds that the growth rate of the US economy from 1973 to 1982 was reduced by only 0.07 percentage points, while a more recent study (Jorgenson and Wilcoxen, 1989) produces a figure of 0.19 for 1974 to 1985 and a long-run reduction of 2.59% in GNP.

A recent study by Manne and Richels (1990) estimates the costs of imposing CO_2 emissions limits using a model that divides the world into five regions: the United States, other OECD nations (OECD), the Soviet Union and Eastern Europe (SU-EE), China and the rest of the world (ROW). If developed countries and SU-EE were to reduce emissions 20% and China and ROW doubled emissions, an equilibrium carbon tax to achieve this result would be \$250 per metric ton of carbon. Most adjustments would be stabilised by 2030 with carbon emissions about 15% above current levels, and emissions in 2100 would be 75% below the level that would be achieved without international agreement. The change in the growth rate of GDP related to achieving this level of emissions is small (0.1 percentage points at most), though the fall in end-year GDP as a percentage of the baseline GDP is larger. It varies from one region to the next, from -1.8 for the OECD (excluding the United States) to -10.5 for China. Since the level of carbon taxes needed to achieve these reductions will vary by region, there is ample scope for emissions trading over the next half-century.

A study by Whalley and Wigle (1990) uses a general equilibrium model to estimate the level of carbon taxes necessary to reduce carbon emissions 50% from 1990 to 2030. The model has only one carbon-based energy resource and five produced goods, three of which are traded among six regions — the United States, the EC, Japan, other OECD countries, energy exporting countries and the rest of the world. To achieve a 50% reduction in emissions, three alternative carbon tax structures were considered: a production-based tax collected by the producers of the carbon resource, a consumption-based tax collected by consuming countries and a global tax collected by an international agency. On a discounted present value basis from 1990 to 2030, the gains and losses vary widely among regions and depending on the type of tax applied. For example, the EC has a net gain of \$1.3 trillion under a consumption-based tax but a loss of \$3.8 trillion under a production-based tax. The gains and losses also vary for the world as a whole, depending on the type of tax system employed. Under a producer-based tax, the world loss is about \$19.5 trillion, but it is only

$9.2 trillion under a consumption-based tax; that is, 2-4% of total world GDP. The greatest regional loss is to oil exporting countries under a consumption-based tax (17% of GDP) and the largest relative gain is to Japan under a consumption-based tax (3%).

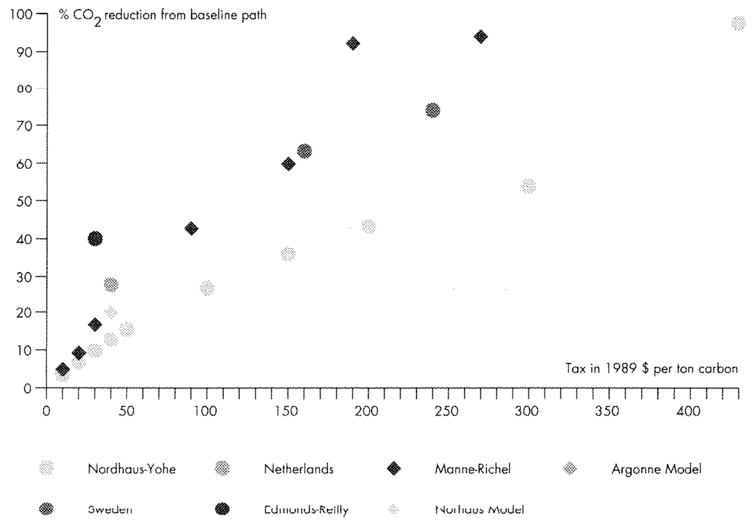
A study by Edmonds and Barns (1990) uses the Edmonds-Reilly model to examine four targets in each of two policy contexts, using alternative carbon tax strategies (end-use tax, producer tax, utility tax). The targets, based on 1988 levels: reduce the rate of emissions by half, stabilise emissions, reduce emissions 20% and reduce emissions 50%. In the first policy context, each target is examined under the assumption that the entire world co-operates to achieve the target; the second context assumes that only OECD countries co-operate to achieve the target. In the latter case, the 20% and 50% reductions were unachievable at any level of carbon tax. If the world co-operated, this analysis suggests, a carbon tax on coal would have to be about $120/metric ton in 1985 prices by 2025 to reduce emissions 50%. If only OECD countries agreed to emissions reductions, stabilising world emissions would require a carbon tax about twelve times as large by 2025, since OECD emissions will account for only 24% of the total by then. If the world co-operates, this goal can be achieved at a total cost of about $150 billion per year in 2025. A 20% reduction could be achieved for $213 billion and a 50% reduction for $715 billion per year. The marginal cost per metric ton of carbon reduced in 2025 is $95 to achieve stabilisation, $136 to achieve a 20% reduction and $436 to achieve a 50% reduction.

Finally, the European model HERMES has been used to explore the effects of an energy tax that would increase the price of energy 20% in the four largest EC member countries (France, Germany, Italy and the United Kingdom). A straightforward introduction of such a tax in 1990, without any accompanying measures, is seen to start a recessionary spiral: Income decreases 2% and causes a fall in demand and investments, while inflation rises and industrial competitiveness decreases. The end result is an average decrease in GDP of 1.47% in 1991 (1.55% in 1995), a 4% fall in employment (0.85%) and a 2.56% price increase (3.69%). Energy consumption declines only 3.69% (5.67%). A second calculation assumes that the energy tax would be accompanied by measures to support energy efficiency investments that would represent about 1% of GDP. In this case, energy consumption would decrease 3% and the impact of the tax on GDP growth would be cushioned, but the inflationary effect remains.

The effect of various carbon taxes considered in several recent modelling exercises on levels of CO_2 emissions is summarised in Figure V.3. Achieving such large reductions of energy-related CO_2 emissions is estimated, in the studies described above, to lead to a reduction of global GDP rates in the range of 0.1 to 0.3 percentage points. Such small differences in GDP growth rates would nevertheless imply large differences in long-run GDP levels (Hoeller *et al.*, 1990).

The macroeconomic effects of carbon taxes should, ideally, be compared to those caused by global warming in the absence of such emission reduction measures. The potential impacts of climate change are uncertain and beyond the scope of this study. They are addressed in the report of Working Group 2 of the Intergovernmental Panel on Climate Change and in the recent study by the OECD examining the socio-economic impacts of climate change (OECD, 1991). These studies suggest that the climate changes associated with a global warming of roughly 2-4°C would result in a world that is different from the world that exists today. Some studies have been carried out on potential physical impacts, but little analysis exists on possible economic effects. Obviously, climate change is likely to involve costs of adaptation, such as sea defence expenditures, as well as other costs, such as dislocation to agriculture. Given the large uncertainties involved, models cannot yet identify regional impacts accurately and it is understandable that economic effects are outlined in qualitative terms only.

Figure V.3
Emission Reductions and Carbon Taxes in Energy Models



Source: Based on Hoeller et al., 1990.

2.2 Other effects and compatibility with broader economic and energy security goals

Many policy instruments may be applied to extend the market potential of energy efficiency improvements and help bridge the gap with the large technical potential for such improvements. Most recent studies examine the effect of taxes, often related to carbon emissions, to achieve this goal. Those studies that examine the role of standards do not attempt to quantify their costs, and the literature on this subject is very limited. Large taxes applied to energy products are likely to have two broad categories of macroeconomic effects. The first arise from the destabilising effects of higher inflation and deflationary drag and are of a short-term nature. The second longer-term effects arise from lower overall productivity growth.

Since fuels are consumed as final goods and are also important inputs in the production of a great variety of products, a large tax on energy would raise the inflation rate, put upward pressure on interest rates and induce a transfer of income from the private to the public sector, all of which can affect the GDP growth rate. Detailed research into the impact of the 1979/80 oil price increase suggests that a $5-10 increase per barrel produces an immediate reduction of GDP of 0.5-1%. In the case of an energy price rise due to a carbon tax, however, the extent to which GDP growth is affected will depend on government fiscal and monetary policies set up as stabilisation measures in an effort to offset the short-term macroeconomic consequences of the tax.

Quite apart from these short-term consequences, which may or may not be offset by stabilisation policies, there are other macroeconomic consequences induced by a large carbon tax that are not as amenable to management. A carbon tax will alter the relative prices of individual fuels as well as the overall level of energy prices relative to the prices of non-energy products. Economic agents will be induced to substitute other inputs for energy. In its most basic form, this means substituting capital and possibly labour for energy. With a fixed amount of capital and labour, national output will initially fall as economic agents adjust to the new system of prices and reduce energy consumption; with a fixed amount of capital and labour and reduced energy consumption, the amount of goods and services produced will fall. While the initial impact of a carbon tax is to reduce income and real GDP, the decline would ultimately be reversed, but this would require an increase in aggregate savings and capital formation. A higher capital-labour ratio in the production process induced by greater savings could in principle offset the effects of substitution away from energy, though the price would have to be forgone consumption. Nevertheless, some of these negative effects could be limited by a gradual introduction of carbon taxes.

The fall in income, consumption and/or real GDP associated with the substitution and reallocation effects are real and long-lasting. They cannot be offset by government initiatives in the same way that the costs associated with the short-term destabilisation effects of high energy prices can be. Moreover, they are not supportive of the development and introduction of technical innovations on which ultimately rest many achievements in the area of energy efficiency as well as pollution control.

It is frequently said that governments can offset the impact of higher energy taxes by reducing other taxes and hence leaving social welfare unchanged (Grubb, 1989). Whether revenue-neutral energy taxes would in fact leave social welfare unchanged is an open question, though individuals and corporations are obviously not indifferent to levels of taxation and some offset would be preferred to none at all. In any case, such a step would not eliminate or offset the economic costs associated with the substitution and resource reallocation effects described above.

The benefits of a carbon tax would primarily arise as a result of the internalisation of external costs. Measuring these benefits, however, is a very difficult undertaking. Political willingness to make drastic economic changes may be wanting, particularly given the uncertain payoffs involved. Global environmental problems are likely to be unresponsive to traditional single-government intervention. National or regional measures, including taxes, can only be successful for non-migratory problems, of which there are very few in the environmental area in the long run. Other factors on a world-wide scale, such as population pressures and deforestation rates, are likely to become increasingly more significant for calculating global concentrations of CO_2.

For this reason, it is essential first to get prices onto a more economic basis. Prices in many IEA countries are still below the level that the pricing principles adopted by the IEA would suggest. Once such problems are eliminated, governments can contemplate additional measures, secure in the knowledge that the left hand is not undermining what the right hand is doing. Many IEA countries have declared their intention to proceed according to what the German Government has called the "Vorsorge Prinzip", which is similar to what the US Government has named the "no regrets" policy — the principle that action should be taken if it is clear that policies are not counterproductive, especially when policies are good for more than one reason. In this respect, improving energy efficiency is a clear priority, though it is important to understand the broader costs and trade-offs involved in achieving significant energy savings.

If there is a need to reduce carbon emissions, raising the price of fuels, by whatever means, will provide a general signal to which individuals and corporations can react by making their own decisions according to local circumstances, needs and constraints. No degree of central planning could perform so well. Large increases in energy prices will achieve some reductions in emission of pollutants, but at a sacrifice of economic efficiency. As pointed out in the conclusion of the Dutch report on energy efficiency potential in 2015 (TNO, 1990), while higher energy prices would have a beneficial effect on the cost-effectiveness of energy efficiency investments, the high investment costs involved in realising a large part of the technical potential for efficiency improvements will be possible only in a healthy economic climate. This particular trade-off is a decision that each government must take with a full understanding of the factors involved. Of particular concern is the goal to achieve the largest possible efficiency improvement (and emission reduction) at lowest cost. The risk of overkill is inherent in the use of taxes to support energy efficiency: The results are unpredictable and may cause excessive costs, though taxes are essentially flexible and successive adjustment and approximation can ultimately produce the results expected.

CHAPTER VI

CONCLUSIONS: AREAS FOR FURTHER WORK

Since 1973, IEA Member countries have been successful in improving the overall efficiency of their economies. Energy intensity improvements in all end-use sectors have played a major role in limiting the growth of CO_2 emissions in IEA countries over the last decade, in some cases more than compensating for the negative effect that changes in the fuel mix of the industrial and buildings sectors may have had on emission levels. By reviewing past energy efficiency developments and policies, a clearer sense of the future scope for energy efficiency is obtained. Clearly, changes in energy prices in the 1970s and 1980s were instrumental in past achievements, though other factors, such as economic growth and technical change, as well as the widespread use of financial instruments and regulatory policy measures in the 1970s and early 1980s, were at work as well.

The scope for further energy efficiency improvements depends not only on technical possibilities to improve energy efficiency, but also on market conditions for the introduction of more energy-efficient technologies. Estimates of future energy efficiency improvements and their impact on energy demand rest on assumptions about equipment costs, energy prices, expected market penetration rates and the effect of policy measures. The practical obstacles to estimating energy efficiency potential tend to be amplified in the case of an assessment on an international level. Where cost data are available, the cost-benefit analysis is country-specific because energy prices differ from one IEA country to the next and because the price of energy-efficient equipment is also variable. As a result, some of the issues discussed in this study are specific to its international approach. Nevertheless, it has revealed the need for further, mainly country-specific work, particularly in terms of improved data and information on energy use and on the cost-effectiveness of energy efficiency investments.

The study does not provide an IEA-wide quantification of the potential for further energy efficiency improvements and their costs. Such work would need to draw on a broad range of national studies of the technical and market factors that are likely to determine the cost-effectiveness of energy efficiency improvements in a range of end-use sectors. Many country-specific studies would also be necessary to assess fully the scope and costs of energy efficient strategies and the macroeconomic impact of measures designed to accelerate the penetration of energy-efficient technologies. While some national studies have been completed which provide such estimates, many more would be necessary to give a complete picture of the situation in the IEA as a whole. Therefore, although it might be tempting to extrapolate these studies into IEA-wide estimates or "supply curves" of energy efficiency potential, such an exercise would be highly theoretical and of limited value.

A number of the methodological issues discussed in this study can be clarified by improvements in basic information about energy end-uses. More information and analysis will also focus attention on what may appear to be points of detail, but may in fact reduce the effectiveness of energy efficiency efforts. Examples include exploring the importance of transaction costs, the validity of consumption test procedures and the importance of rebound effects in translating energy efficiency improvements into demand reductions.

While it is possible to carry out theoretical projections of the potential for energy efficiency improvements at a national or regional level, this belies the reality that reliable information on energy demand and efficiency and a better understanding of the many non-technical factors, including the evaluation of cost-effectiveness, that influence energy use are areas of relative weakness in many IEA countries. In many cases, this sort of information can only be provided by extensive, regular surveying. Allocation of budget and staff to these tasks has not always been a priority. Indeed, it appears that detailed data on the way energy is used to provide services and goods are often unavailable and that as a result, stronger cause and effect relationships cannot be fully accessed. For some countries, this lack of information is a serious concern. Many governments are assigning a major role to energy efficiency in policies to meet national targets and other commitments to limit greenhouse gas emissions.

Four areas which could benefit from further work are outlined below. These are: basic data on energy consumption and efficiency levels; information on equipment costs; the assessment of consumer behaviour and the evaluation of energy efficiency investments; and the evaluation of policy measures, their effectiveness and their costs.

Basic data on energy consumption and efficiency levels

In some areas and for some countries, there are few subsectoral detailed data on energy consumption. For instance, while figures on gasoline and diesel deliveries are readily available, the actual use of these fuels in the different road transport subsectors, such as passenger cars and goods transport, is not definitely known in most IEA countries. In addition, current levels of efficiency are often poorly known. A major pitfall is that efficiency is often measured in conditions that do not correspond to the equipment's real operating conditions. When such efficiency measures are extrapolated to a whole end-use, their effect on energy demand can be overestimated. This problem was discussed in Chapter III, when it was pointed out that the fuel economy of new cars measured by standard tests could be well above that observed in real driving conditions. There is therefore substantial scope for broadening the information base on which rest estimates of the potential for energy efficiency improvements.

Information on equipment costs

Information on the costs associated with energy-efficient technologies is essential in order to carry out a comparative analysis of the various technological options identified. In the industrial sector, for instance, it was found that the most significant stumbling block is the lack of information on equipment costs. Equipment-based cost data are simply not adequate. Although some countries are collecting this information for some end-use sectors, the sample is too small and not widely enough distributed among countries to allow for generalisation. In addition, information or transaction cost are often overlooked.

Assessment of consumer behaviour and the evaluation of energy efficiency investments

The market potential for energy efficiency improvements varies according to different combinations of market barriers and policy measures taken to overcome them. The analysis of the market potential is therefore inseparable from a thorough understanding of present market barriers. This contributes to a more realistic assessment of the way the market takes up technical opportunities to improve energy efficiency, on which, ultimately, practical policy recommendations can be based.

It is therefore essential to gain a better understanding than we have of the factors that influence the way consumers perceive energy costs and benefits. Over the last 15 years, private consumers, energy utilities and public and governmental bodies have become aware of the need to evaluate end-use energy efficiency investments in order to set priorities and reach decisions concerning the implementation of energy efficiency improvements. These various categories of economic actors have adopted different perspectives in their evaluation of these investments and this is reflected in different points of view as to what constitutes a cost-effective energy efficiency improvement. A focused examination of the financial evaluation methods used by different types of end-users can provide a better understanding of how consumers consider energy efficiency investments and reach financial decisions on energy efficiency improvements. It can also throw some light on the attractiveness of policies and measures aimed at improving the energy efficiency of the economies of IEA Member countries. Such an analysis is also indispensable for assessing the macroeconomic impacts of energy efficiency measures, for instance on economic growth, foreign exchange expenditure and trade.

The relationship between energy demand and improvements in energy efficiency is not a straightforward one. In the past, reductions in energy demand related to energy efficiency improvements have often been compensated by the effect of other factors. Financial savings due to improved energy efficiency increase disposable income, which can then be devoted to other energy-consuming activities. Evaluations of energy efficiency potential may therefore overestimate actual energy demand reductions. The future role of energy efficiency in emission reduction strategies depends on the extent to which efficiency improvements are actually translated into energy demand and emission reductions by consumer behaviour. This is therefore an area where further work can make an important contribution to ensuring that energy efficiency efforts can play a full part in reducing CO_2 emissions from energy activities.

Evaluation of policy measures, their effectiveness and their costs

All IEA countries have in the past taken measures to support the improvement in the energy efficiency of their economies, though they have chosen different approaches, with different degrees of success. These measures include information, regulation, price setting and taxation, economic incentives and support for research and development. The degree of effectiveness and the overall cost of each policy measure vary according to country-specific circumstances, such as climate, resource endowment, energy price levels and economic activity. Those responsible for running energy efficiency programmes have often found it difficult to establish clear cause and effect relationships, i.e. to attribute given energy demand reductions to price effects or to a specific policy measure, and programmes have not always been fully or adequately evaluated.

This evaluation can provide essential information to governments that need to know with some assurance the effectiveness of policy measures aimed at improving energy efficiency and implemented to meet commitments to reduce emissions of CO_2. In many cases, though it is recognised that greater efforts to accelerate energy efficiency improvements are essential, the effectiveness of the policy portfolio of subsidies, regulations and action by public utilities remains tentative. In particular, the systematic evaluation of policy measures can reduce the considerable uncertainty that still exists about the multiplier effect of public funds. This evaluation is most effective when integrated from the start into energy efficiency programmes by those responsible for their management.

The analysis presented in Chapter IV concludes that a large part of the significant potential for technical efficiency improvements is not being taken up by the market. Therefore, market conditions must change markedly for even part of this potential to be realised. A number of policy measures would be necessary in order to ensure that energy efficiency improvements will contribute fully to reducing energy demand and related pollutant emissions. These policy measures, such as energy taxes or regulations, entail costs to the private sector as well as to the public sector. Their costs, though sometimes hidden, should not be underestimated and need to be carefully assessed. Depending on their scale and nature, they can have a significant macroeconomic effect, on economic growth in particular.

While there are many forecasting exercises that translate efficiency improvements into energy demand and future levels of CO_2 emissions, most are designed only to broadly explore possible scenarios, and relatively few attempt to quantify the overall costs involved. In some cases, though costs are given, they are at best underestimated because they do not include the cost of the policy measures involved for all parties concerned. The focus in most recent studies is on energy taxes, particularly carbon taxes, rather than other policy instruments such as regulation. It is also important to assess the full cost of policy measures, including governmental costs such as administrative costs, and indirect costs such as those borne by equipment manufacturers.

ANNEX 1 :
IEA END-USE CO_2 EMISSIONS

Table A1.1

CARBON EMISSIONS, IEA (1988)

Mt carbon

	COAL	OTHER SOLIDS	OIL	GAS	ELECTRICITY	TOTAL	% OF TOTAL EMISSIONS
TPER	**890.08**	**99.20**	**1 185.06**	**449.22**	—	**2 623.56**	**100.00**
ELECTRICITY GENERATION	682.43	4.03	105.61	87.28	—	879.37	33.52
TFC	207.65	95.17	1 079.45	361.93	879.37	2 623.56	100.00
INDUSTRY	**180.09**	**59.44**	**143.57**	**153.45**	**359.25**	**895.80**	**34.14**
Iron & Steel	100.26	n.a.	n.a.	n.a.	41.64	n.a.	n.a.
Chemical	19.55	n.a.	n.a.	n.a.	67.98	n.a.	n.a.
Non-ferrous	5.51	n.a.	n.a.	n.a.	39.62	n.a.	n.a.
Non-metallic	24.17	n.a.	n.a.	n.a.	18.46	n.a.	n.a.
Transp. Equipm.	1.49	n.a.	n.a.	n.a.	15.44	n.a.	n.a.
Machinery	2.06	n.a.	n.a.	n.a.	34.93	n.a.	n.a.
Textile	1.52	n.a.	n.a.	n.a.	14.12	n.a.	n.a.
Food Prod.	6.08	n.a.	n.a.	n.a.	21.93	n.a.	n.a.
Paper, Pulp & Printing	10.61	n.a.	n.a.	n.a.	44.76	n.a.	n.a.
Other	8.84	n.a.	n.a.	n.a.	60.45	n.a.	n.a.
TRANSPORT	**0.15**	**0.00**	**726.87**	**0.29**	**10.38**	**737.68**	**28.12**
Air	0.00	0.00	94.63	0.01	0.00	94.64	3.61
Road	0.00	0.00	600.64	0.28	0.00	600.91	22.90
Rail	0.07	0.00	15.11	0.01	10.38	25.56	0.97
Other	0.08	0.00	16.49	0.01	0.00	16.57	0.63
OTHER	**27.42**	**35.73**	**208.98**	**208.18**	**509.76**	**990.07**	**37.74**
Agriculture	0.24	0.26	33.17	2.46	6.92	43.04	1.64
Commercial/Public	4.75	0.15	62.51	59.45	224.56	351.42	13.39
Residential	17.51	35.32	100.26	139.48	277.36	569.93	21.72
Other	4.92	0.00	13.05	6.80	0.92	25.70	0.98
Emission Factors:							
Mt carbon/Mtoe							
primary energy basis	1.09	0.89	0.84	0.64	—	—	—
delivered energy basis	1.14	0.89	0.89	0.73	1.96	—	—

Table A1.2

CARBON EMISSIONS, AUSTRALIA (1988)

Mt carbon

	COAL	OTHER SOLIDS	OIL	GAS	ELECTRICITY	TOTAL	% OF TOTAL EMISSIONS
TPER	**35.48**	**3.68**	**22.67**	**8.15**	—	**69.98**	**100.00**
ELECTRICITY GENERATION	30.47	0.12	0.45	2.27	—	33.30	47.58
TFC	**5.01**	**3.56**	**22.22**	**5.88**	**33.30**	**69.98**	**100.00**
INDUSTRY	**4.76**	**2.04**	**2.30**	**4.17**	**14.99**	**28.26**	**40.39**
Iron & Steel	1.65	0.00	0.03	0.30	1.24	3.22	4.61
Chemical	0.24	0.17	0.07	0.71	1.01	2.19	3.41
Non-ferrous	1.45	0.03	0.80	1.17	6.71	10.14	14.49
Non-metallic	0.53	0.02	0.07	0.94	0.74	2.30	3.29
Transp. Equipm.	0.00	0.00	0.01	0.10	0.37	0.48	0.68
Machinery	0.01	0.00	0.02	0.12	0.70	0.86	1.23
Textiles	0.05	0.00	0.02	0.11	0.50	0.68	0.97
Food Prod.	0.34	1.51	0.13	0.38	1.17	3.54	5.00
Paper, Pulp & Printing	0.34	0.16	0.04	0.32	1.11	1.96	2.80
Other	0.18	0.15	1.11	0.02	1.48	2.79	3.99
TRANSPORT	**0.08**	**0.00**	**18.46**	**0.01**	**0.44**	**18.99**	**27.13**
Air	0.00	0.00	2.12	0.01	0.00	2.13	3.04
Road	0.00	0.00	15.18	0.00	0.00	15.18	21.70
Rail	0.00	0.00	0.55	0.00	0.44	0.99	1.41
Other	0.08	0.00	0.60	0.00	0.00	0.67	0.96
OTHER	**0.18**	**1.52**	**1.46**	**1.71**	**17.87**	**22.74**	**32.49**
Agriculture	0.00	0.00	0.94	0.00	0.57	1.51	2.16
Commercial/Public	0.16	0.02	0.20	0.47	6.84	7.68	10.97
Residential	0.02	1.50	0.32	1.24	10.46	13.55	19.36
Other	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Emission Factors: Mt carbon/Mtoe							
primary energy basis	1.10	0.89	0.84	0.64	—	—	—
delivered energy basis	1.17	0.89	0.87	0.75	3.35	—	—

Table A1.3

CARBON EMISSIONS, AUSTRIA (1988)

Mt carbon

	COAL	OTHER SOLIDS	OIL	GAS	ELECTRICITY	TOTAL	% OF TOTAL EMISSIONS
TPER	**4.08**	**1.99**	**7.78**	**2.62**	—	**16.47**	**100.00**
ELECTRICITY GENERATION	1.21	0.17	0.34	0.73	—	2.45	14.88
TFC	**2.87**	**1.82**	**7.44**	**1.89**	**2.45**	**16.47**	**100.00**
INDUSTRY	**1.84**	**0.42**	**0.93**	**0.89**	**1.03**	**5.11**	**31.03**
Iron & Steel	1.51	0.00	0.14	0.22	0.11	1.98	12.02
Chemical	0.02	0.04	0.11	0.13	0.18	0.48	2.91
Non-ferrous	0.01	0.00	0.03	0.00	0.13	0.17	1.03
Non-metallic	0.22	0.00	0.19	0.14	0.09	0.63	3.83
Transp. Equipm.	0.00	0.00	0.01	0.02	0.03	0.06	0.36
Machinery	0.00	0.00	0.03	0.02	0.10	0.15	0.91
Textiles	0.00	0.00	0.05	0.03	0.04	0.13	0.79
Food Prod.	0.00	0.00	0.11	0.07	0.06	0.24	1.46
Paper, Pulp & Printing	0.05	0.32	0.12	0.17	0.04	0.20	1.21
Other	0.04	0.05	0.14	0.09	0.25	1.07	6.50
TRANSPORT	**0.02**	**0.00**	**4.45**	**0.02**	**0.14**	**4.64**	**28.17**
Air	0.00	0.00	0.27	0.00	0.00	0.27	1.64
Road	0.00	0.00	4.11	0.01	0.00	4.12	25.02
Rail	0.02	0.00	0.06	0.00	0.14	0.24	1.46
Other	0.00	0.00	0.00	0.00	0.00	0.00	0.00
OTHER	**1.00**	**1.39**	**2.07**	**0.98**	**1.28**	**6.72**	**40.80**
Agriculture	0.00	0.00	0.00	0.00	0.08	0.08	0.49
Commercial/Public	0.00	0.00	0.00	0.00	0.54	0.54	3.28
Residential	1.00	1.39	2.05	0.98	0.65	6.08	36.92
Other	0.00	0.00	0.02	0.00	0.00	0.02	0.12
Emission Factors: Mt carbon/Mtoe							
primary energy basis	1.11	0.89	0.84	0.64	—	—	—
delivered energy basis	1.22	0.89	0.90	0.70	0.71	—	—

Table A1.4

CARBON EMISSIONS, BELGIUM (1988)

Mt carbon

	COAL	OTHER SOLIDS	OIL	GAS	ELECTRICITY	TOTAL	% OF TOTAL EMISSIONS
TPER	**10.03**	**0.23**	**14.24**	**4.30**	—	**28.80**	**100.00**
ELECTRICITY GENERATION	4.48	0.23	0.27	0.46	—	5.44	18.89
TFC	**5.54**	**0.00**	**13.97**	**3.84**	**5.44**	**28.80**	**100.00**
INDUSTRY	**4.89**	**0.00**	**1.91**	**1.67**	**2.89**	**11.37**	**39.48**
Iron & Steel	4.10	0.00	0.21	0.39	0.50	5.21	18.09
Chemical	0.11	0.00	0.47	0.45	0.95	1.98	6.88
Non-ferrous	0.02	0.00	0.06	0.05	0.21	0.34	1.18
Non-metallic	0.49	0.00	0.18	0.29	0.18	1.15	3.99
Transp. Equipm.	0.00	0.00	0.00	0.05	0.09	0.14	0.49
Machinery	0.02	0.00	0.11	0.01	0.20	0.35	1.22
Textiles	0.00	0.00	0.05	0.03	0.15	0.24	0.83
Food Prod.	0.09	0.00	0.33	0.08	0.25	0.75	2.60
Paper, Pulp & Printing	0.02	0.00	0.08	0.05	0.20	0.34	1.18
Other	0.04	0.00	0.42	0.27	0.16	0.87	3.02
TRANSPORT	**0.00**	**0.00**	**6.79**	**0.00**	**0.12**	**6.92**	**24.03**
Air	0.00	0.00	0.64	0.00	0.00	0.64	2.22
Road	0.00	0.00	5.95	0.00	0.00	5.95	20.66
Rail	0.00	0.00	0.07	0.00	0.12	0.19	0.66
Other	0.00	0.00	0.13	0.00	0.00	0.13	0.45
OTHER	**0.65**	**0.00**	**5.27**	**2.17**	**2.42**	**10.51**	**36.49**
Agriculture	0.00	0.00	0.53	0.00	0.00	0.53	1.84
Commercia/Public	0.00	0.00	1.22	0.62	0.71	2.55	8.85
Residential	0.65	0.00	3.52	1.55	1.71	7.43	25.80
Other	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Emission Factors: Mt carbon/Mtoe							
primary energy basis	1.11	0.89	0.84	0.64	—	—	—
delivered erergy basis	1.22	0.89	0.91	0.64	1.17	—	—

Table A1.5

CARBON EMISSIONS, CANADA (1988)

Mt carbon

	COAL	OTHER SOLIDS	OIL	GAS	ELECTRICITY	TOTAL	% OF TOTAL EMISSIONS
TPER	**29.73**	**6.24**	**56.70**	**30.84**	—	**123.51**	**100.00**
ELECTRICITY GENERATION	23.65	0.27	2.29	1.17	—	27.37	22.16
TFC	**6.08**	**5.97**	**54.41**	**29.67**	**27.37**	**123.51**	**100.00**
INDUSTRY	**6.00**	**5.97**	**6.83**	**13.85**	**11.86**	**44.52**	**36.05**
Iron & Steel	4.15	0.00	0.38	1.16	0.68	6.36	5.15
Chemical	0.30	0.00	0.36	2.58	1.25	4.49	3.64
Non-ferrous	0.35	0.00	0.30	0.48	2.35	3.48	2.82
Non-metallic	0.72	0.00	0.38	0.29	0.41	1.79	1.45
Transp. Equipm.	0.00	0.00	0.08	0.94	0.21	1.24	1.00
Machinery	0.00	0.00	0.07	0.81	0.32	1.20	0.97
Textiles	0.00	0.00	0.10	0.51	0.16	0.77	0.62
Food Prod.	0.00	0.00	0.40	1.81	0.45	2.66	2.15
Paper, Pulp & Printing	0.08	0.00	1.70	1.60	3.46	6.83	5.53
Other	0.41	5.97	3.05	3.68	2.57	15.70	12.71
TRANSPORT	**0.00**	**0.00**	**37.86**	**0.04**	**0.22**	**38.13**	**30.87**
Air	0.00	0.00	4.06	0.00	0.00	4.06	3.29
Road	0.00	0.00	30.50	0.04	0.00	30.54	24.73
Rail	0.00	0.00	1.79	0.00	0.22	2.01	1.63
Other	0.00	0.00	1.51	0.00	0.00	1.51	1.22
OTHER	**0.08**	**0.00**	**9.71**	**15.78**	**15.29**	**40.86**	**33.08**
Agriculture	0.00	0.00	1.60	0.36	0.57	2.54	2.06
Commercial/Public	0.01	0.00	3.89	6.54	6.79	17.23	13.95
Residential	0.07	0.00	4.22	8.88	7.93	21.10	17.08
Other	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Emission Factors: Mt carbon/Mtoe							
primary energy basis	1.08	0.89	0.84	0.64	—	—	—
delivered energy basis	1.09	0.89	0.91	0.81	0.76	—	—

Table A1.6

CARBON EMISSIONS, DENMARK (1988)

Mt carbon

	COAL	OTHER SOLIDS	OIL	GAS	ELECTRICITY	TOTAL	% OF TOTAL EMISSIONS
TPER	**7.53**	**0.75**	**7.65**	**0.89**	—	**16.82**	**100.00**
ELECTRICITY GENERATION	6.82	0.00	0.29	0.08	—	7.19	42.75
TFC	**0.70**	**0.75**	**7.37**	**0.81**	**7.19**	**16.82**	**100.00**
INDUSTRY	**0.37**	**0.12**	**0.98**	**0.25**	**2.17**	**3.90**	**23.19**
Iron & Steel	0.00	0.00	0.04	0.02	0.19	0.25	1.49
Chemical	0.00	0.00	0.11	0.04	0.39	0.54	3.21
Non-ferrous	0.00	0.00	0.00	0.01	0.00	0.01	0.06
Non-metallic	0.16	0.00	0.18	0.06	0.18	0.58	3.45
Transp. Equipm.	0.00	0.00	0.02	0.00	0.09	0.11	0.65
Machinery	0.00	0.00	0.12	0.01	0.26	0.39	2.32
Textiles	0.00	0.00	0.03	0.01	0.08	0.13	0.77
Food Prod.	0.11	0.00	0.28	0.07	0.51	0.98	5.83
Paper, Pulp & Printing	0.04	0.00	0.04	0.02	0.17	0.27	1.61
Other	0.05	0.12	0.15	0.00	0.33	0.63	3.75
TRANSPORT	**0.00**	**0.00**	**3.61**	**0.00**	**0.05**	**3.66**	**21.76**
Air	0.00	0.00	0.67	0.00	0.00	0.67	3.98
Road	0.00	0.00	2.52	0.00	0.00	2.52	14.98
Rail	0.00	0.00	0.10	0.00	0.05	0.15	0.89
Other	0.00	0.00	0.31	0.00	0.00	0.31	1.84
OTHER	**0.33**	**0.63**	**2.77**	**0.56**	**4.97**	**9.27**	**55.11**
Agriculture	0.08	0.16	0.20	0.02	0.59	1.04	6.18
Commercial/Public	0.00	0.00	0.23	0.04	1.98	2.26	13.44
Residential	0.24	0.47	1.99	0.50	2.29	5.50	32.70
Other	0.01	0.00	0.35	0.00	0.11	0.47	2.79
Emission Factors:							
Mt carbon/Mtoe							
primary energy basis	1.11	0.89	0.84	0.64	—	—	—
delivered energy basis	1.11	0.89	0.89	0.65	2.97	—	—

Table A1.7

CARBON EMISSIONS, GERMANY (1988)

Mt carbon

	COAL	OTHER SOLIDS	OIL	GAS	ELECTRICITY	TOTAL	% OF TOTAL EMISSIONS
TPER	**82.35**	1.79	**84.23**	**27.49**	—	**195.86**	**100.00**
ELECTRICITY GENERATION	60.19	0.87	2.12	4.81	—	68.00	34.72
TFC	**22.16**	**0.92**	**82.11**	**22.67**	**68.00**	**195.86**	**100.00**
INDUSTRY	**18.82**	**0.09**	**8.00**	**9.32**	**32.62**	**68.86**	35.16
Iron & Steel	12.48	0.00	0.89	1.48	4.29	19.15	9.78
Chemical	2.81	0.00	1.64	2.67	9.27	16.38	8.36
Non-ferrous	0.27	0.00	0.19	0.34	3.51	4.31	2.20
Non-metallic	1.99	0.00	1.20	1.28	1.78	6.25	3.19
Transp. Equipm.	0.11	0.00	0.32	0.75	2.20	3.38	1.73
Machinery	0.19	0.00	0.97	0.87	1.20	3.22	1.64
Textiles	0.13	0.00	0.43	0.33	1.04	1.93	0.99
Food Prod.	0.26	0.00	1.12	0.90	1.71	4.00	2.04
Paper, Pulp & Printing	0.50	0.03	0.70	0.45	2.62	4.31	2.20
Other	0.09	0.06	0.53	0.25	5.00	5.92	3.02
TRANSPORT	**0.00**	**0.00**	**42.17**	**0.00**	**2.01**	**44.18**	**22.56**
Air	0.00	0.00	4.08	0.00	0.00	4.08	2.08
Road	0.00	0.00	37.19	0.00	0.00	37.19	18.99
Rail	0.00	0.00	0.38	0.00	2.09	2.36	1.20
Other	0.00	0.00	0.52	0.00	0.00	0.52	0.27
OTHER	**3.33**	**0.82**	**31.94**	**13.36**	**33.37**	**82.82**	**42.29**
Agriculture	0.12	0.08	1.31	0.09	1.35	2.95	1.51
Commercial/Public	0.42	0.05	11.22	3.10	14.02	28.81	14.71
Residential	2.34	0.69	18.77	8.96	18.00	48.75	24.89
Other	0.46	0.00	0.65	1.20	0.00	2.30	1.17
Emission Factors:							
Mt carbon/Mtoe							
primary energy basis	1.11	0.89	0.84	0.64	—	—	—
delivered energy basis	1.15	0.90	0.88	0.70	2.14	—	—

Table A1.8

CARBON EMISSIONS, GREECE (1988)

Mt carbon

	COAL	OTHER SOLIDS	OIL	GAS	ELECTRICITY	TOTAL	% OF TOTAL EMISSIONS
TPER	**8.23**	**0.45**	**9.53**	**0.03**	—	**18.23**	**100.00**
ELECTRICITY GENERATION	6.91	0.00	1.28	0.02	—	8.21	45.04
TFC	**1.32**	**0.45**	**8.25**	**0.01**	**8.21**	**18.23**	**100.00**
INDUSTRY	**1.27**	**0.00**	**1.58**	**0.01**	**3.59**	**6.45**	**35.38**
Iron & Steel	0.00	0.00	0.07	0.00	0.32	0.39	2.14
Chemical	0.16	0.00	0.10	0.09	0.43	0.77	4.22
Non-ferrous	0.16	0.00	0.18	0.00	0.96	1.30	7.13
Non-metallic	0.94	0.00	0.23	0.00	0.53	1.70	9.33
Transp. Equipm.	0.00	0.00	0.00	0.00	0.04	0.04	0.22
Machinery	0.00	0.00	0.00	0.00	0.11	0.11	0.60
Textiles	0.01	0.00	0.12	0.00	0.18	0.31	1.70
Food Prod.	0.00	0.00	0.21	0.00	0.14	0.35	1.92
Paper, Pulp & Printing	0.00	0.00	0.07	0.00	0.32	0.39	2.14
Other	0.00	0.00	0.59	0.00	0.50	1.09	5.98
TRANSPORT	**0.00**	**0.00**	**4.59**	**0.00**	**0.07**	**4.66**	**25.56**
Air	0.00	0.00	1.00	0.00	0.00	1.00	5.49
Road	0.00	0.00	3.15	0.00	0.00	3.15	17.28
Rail	0.00	0.00	0.05	0.00	0.07	0.12	0.66
Other	0.00	0.00	0.40	0.00	0.00	0.40	2.19
OTHER	**0.04**	**0.45**	**2.09**	**0.01**	**4.58**	**7.17**	**39.33**
Agriculture	0.00	0.00	0.80	0.00	0.36	1.15	6.31
Commercial/Public	0.01	0.04	0.06	0.00	1.53	1.64	9.00
Residential	0.03	0.40	1.19	0.00	2.66	4.29	23.53
Other	0.00	0.00	0.03	0.00	0.00	0.03	0.16
Emission Factors: Mt carbon/Mtoe							
primary energy basis	1.11	0.89	0.84	0.64	—	—	—
delivered energy basis	1.11	0.89	0.87	0.85	3.55	—	—

Table A1.9

CARBON EMISSIONS, IRELAND (1988)

Mt carbon

	COAL	OTHER SOLIDS	OIL	GAS	ELECTRICITY	TOTAL	% OF TOTAL EMISSIONS
TPER	**2.58**	1.24	**3.33**	**0.76**	—	**7.91**	**100.00**
ELECTRICITY GENERATION	1.26	0.70	0.22	0.49	—	2.67	33.75
TFC	**1.32**	**0.54**	**3.11**	**0.55**	**2.67**	**7.91**	**100.00**
INDUSTRY	**0.48**	**0.02**	**0.76**	**0.19**	**1.00**	**2.46**	**31.10**
Iron & Steel	0.00	0.00	0.00	0.01	0.12	0.13	1.64
Chemical	0.00	0.00	0.10	0.06	0.13	0.29	3.67
Non-ferrous	0.00	0.00	0.17	0.00	0.00	0.17	2.15
Non-metallic	0.00	0.00	0.05	0.00	0.11	0.16	2.02
Transp. Equipm.	0.00	0.00	0.00	0.00	0.01	0.01	0.13
Machinery	0.00	0.00	0.08	0.00	0.10	0.18	2.28
Textiles	0.00	0.00	0.03	0.00	0.05	0.08	1.01
Food Prod.	0.00	0.00	0.13	0.07	0.27	0.48	6.07
Paper, Pulp & Printing	0.00	0.00	0.02	0.00	0.02	0.04	0.51
Other	0.48	0.02	0.17	0.05	0.18	0.91	11.50
TRANSPORT	**0.00**	**0.00**	**1.64**	**0.00**	**0.00**	**1.64**	**20.73**
Air	0.00	0.00	0.33	0.00	0.00	0.33	4.17
Road	0.00	0.00	1.26	0.00	0.00	1.26	15.93
Rail	0.00	0.00	0.04	0.00	0.00	0.04	0.51
Other	0.00	0.00	0.00	0.00	0.00	0.00	0.00
OTHER	**0.84**	**0.53**	**0.71**	**0.08**	**1.66**	**3.82**	**48.29**
Agriculture	0.00	0.00	0.18	0.00	0.00	0.18	2.28
Commercial/Public	0.03	0.02	0.26	0.04	0.61	0.96	12.14
Residential	0.80	0.51	0.28	0.04	1.05	2.68	33.88
Other	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Emission Factors: Mt carbon/Mtoe							
primary energy basis	1.11	0.89	0.84	0.64	—	—	—
delivered energy basis	1.07[1]	1.05	0.88	0.65	2.90	—	—

1. Due to an input of 0.19 Mtoe of peat briquettes at the transformation stage.

Table A1.10

CARBON EMISSIONS, ITALY (1988)

Mt carbon

	COAL	OTHER SOLIDS	OIL	GAS	ELECTRICITY	TOTAL	% OF TOTAL EMISSIONS
TPER	**15.42**	**1.02**	**68.17**	**20.55**	—	**105.17**	**100.00**
ELECTRICITY GENERATION	9.31	0.21	17.46	4.27	—	31.25	29.71
TFC	**6.11**	**0.82**	**50.71**	**16.29**	**31.25**	**105.17**	**100.00**
INDUSTRY	**5.98**	**0.12**	**8.71**	**7.33**	**16.48**	**38.63**	**36.73**
Iron & Steel	5.00	0.00	0.19	1.13	2.98	9.30	8.84
Chemical	0.18	0.00	2.42	1.61	3.99	8.20	7.80
Non-ferrous	0.04	0.00	0.03	0.12	0.94	1.13	1.07
Non-metallic	0.62	0.11	2.91	1.53	1.61	6.78	6.45
Transp. Equipm.	0.00	0.00	0.00	0.00	0.57	0.57	0.54
Machinery	0.07	0.00	0.91	0.56	2.03	3.56	3.38
Textiles	0.00	0.00	0.60	0.29	1.40	2.30	2.19
Food Prod.	0.03	0.01	0.45	0.62	1.08	2.20	2.09
Paper, Pulp & Printing	0.00	0.00	0.32	0.48	1.05	1.85	1.76
Other	0.04	0.00	0.88	0.99	0.85	2.75	2.61
TRANSPORT	**0.00**	**0.00**	**28.30**	**0.15**	**0.94**	**29.38**	**27.94**
Air	0.00	0.00	1.47	0.00	0.00	1.47	1.40
Road	0.00	0.00	26.13	0.15	0.00	26.28	24.99
Rail	0.00	0.00	0.19	0.00	0.94	1.12	1.06
Other	0.00	0.00	0.51	0.00	0.00	0.51	0.48
OTHER	**0.13**	**0.69**	**13.69**	**8.81**	**13.83**	**37.15**	**35.32**
Agriculture	0.00	0.00	2.18	0.01	0.59	2.78	2.64
Commercial/Public	0.00	0.00	1.06	0.00	5.46	6.52	6.20
Residential	0.13	0.69	10.45	8.80	7.77	27.84	26.47
Other	0.00	0.00	0.01	0.00	0.00	0.01	0.01
Emission Factors:							
Mt carbon/Mtoe							
primary energy basis	1.11	0.89	0.84	0.64	—	—	—
delivered energy basis	1.27	0.92	0.91	0.65	1.83	—	—

Table A1.11

CARBON EMISSIONS, JAPAN (1988)

Mt carbon

	COAL	OTHER SOLIDS	OIL	GAS	ELECTRICITY	TOTAL	% OF TOTAL EMISSIONS
TPER	**81.00**	**0.00**	**162.95**	**24.11**	—	**268.06**	**100.00**
ELECTRICITY GENERATION	30.47	0.00	39.28	16.23	—	85.98	32.07
TFC	**50.53**	**0.00**	**123.66**	**7.89**	**85.98**	**268.06**	**100.00**
INDUSTRY	**50.24**	**0.00**	**27.49**	**2.21**	**50.12**	**130.05**	**48.52**
Iron & Steel	39.38	0.00	1.93	0.39	9.29	50.99	19.02
Chemical	1.51	0.00	3.19	0.29	6.52	11.51	4.29
Non-ferrous	0.20	0.00	0.40	0.00	1.71	2.31	0.86
Non-metallic	6.41	0.00	2.93	0.00	2.22	11.56	4.31
Transp. Equipm.	0.00	0.00	0.00	0.00	2.62	2.62	0.98
Machinery	0.00	0.00	0.00	0.00	3.52	3.52	1.31
Textiles	0.00	0.00	2.40	0.00	0.90	3.31	1.23
Food Prod.	0.00	0.00	2.17	0.00	1.34	3.51	1.31
Paper, Pulp & Printing	1.17	0.00	0.74	0.00	3.63	5.54	2.07
Other	1.57	0.00	13.72	1.53	18.36	35.18	13.12
TRANSPORT	**0.00**	**0.00**	**57.69**	**0.00**	**2.33**	**60.02**	**22.39**
Air	0.00	0.00	2.47	0.00	0.00	2.47	0.92
Road	0.00	0.00	50.07	0.00	0.00	50.07	18.68
Rail	0.00	0.00	0.97	0.00	2.33	3.30	1.23
Other	0.00	0.00	4.18	0.00	0.00	4.18	1.56
OTHER	**0.29**	**0.00**	**38.49**	**5.68**	**33.53**	**77.99**	**29.09**
Agriculture	0.00	0.00	4.94	0.00	0.18	5.12	1.91
Commercial/Public	0.00	0.00	13.25	1.22	12.47	26.94	10.05
Residential	0.29	0.00	10.63	4.42	20.88	36.22	13.51
Other	0.00	0.00	9.68	0.04	0.00	9.72	3.63
Emission Factors:							
Mt carbon/Mtoe							
primary energy basis	1.10	0.89	0.84	0.64	—	—	—
delivered energy basis	1.34	n.a.	0.89	0.58[1]	1.50	—	—

1. Due to transformation of coal into 4.19 Mtoe of gas.

Table A1.12

CARBON EMISSIONS, LUXEMBOURG (1988)

Mt carbon

	COAL	OTHER SOLIDS	OIL	GAS	ELECTRICITY	TOTAL	% OF TOTAL EMISSIONS
TPER	**1.23**	**0.02**	**1.13**	**0.23**	—	**2.62**	**100.00**
ELECTRICITY GENERATION	0.13	0.02	0.01	0.00	—	0.17	6.49
TFC	**1.11**	**0.00**	**1.12**	**0.22**	**0.17**	**2.62**	**100.00**
INDUSTRY	**1.10**	**0.00**	**0.22**	**0.12**	**0.11**	**1.55**	**59.16**
Iron & Steel	1.00	0.00	0.15	0.08	0.05	1.28	48.85
Chemical	0.00	0.00	0.04	0.00	0.02	0.06	2.29
Non-ferrous	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Non-metallic	0.00	0.00	0.00	0.00	0.01	0.01	0.38
Transp. Equipm.	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Machinery	0.00	0.00	0.00	0.00	0.01	0.01	0.38
Textiles	0.00	0.00	0.00	0.00	0.01	0.01	0.38
Food Prod.	0.00	0.00	0.01	0.00	0.00	0.01	0.38
Paper, Pulp & Printing	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Other	0.09	0.00	0.02	0.05	0.00	0.16	6.11
TRANSPORT	**0.00**	**0.00**	**0.64**	**0.00**	**0.00**	**0.64**	**24.43**
Air	0.00	0.00	0.09	0.00	0.00	0.09	3.44
Road	0.00	0.00	0.54	0.00	0.00	0.54	20.61
Rail	0.00	0.00	0.01	0.00	0.00	0.01	0.38
Other	0.00	0.00	0.00	0.00	0.00	0.00	0.00
OTHER	**0.01**	**0.00**	**0.26**	**0.10**	**0.06**	**0.43**	**16.41**
Agriculture	0.00	0.00	0.01	0.00	0.00	0.01	0.38
Commercial/Public	0.00	0.00	0.00	0.10	0.03	0.13	4.96
Residential	0.01	0.00	0.26	0.00	0.03	0.29	11.07
Other	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Emission Factors: Mt carbon/Mtoe							
primary energy basis	1.11	0.89	0.84	0.64	—	—	—
delivered energy basis	1.13	0.89	0.84	0.64	0.49	—	—

Table A1.13

CARBON EMISSIONS, NETHERLANDS (1988)

Mt carbon

	COAL	OTHER SOLIDS	OIL	GAS	ELECTRICITY	TOTAL	% OF TOTAL EMISSIONS
TPER	**9.00**	**0.16**	**14.55**	**18.06**	—	**41.77**	**100.00**
ELECTRICITY GENERATION	6.37	0.16	0.77	4.80	—	12.10	28.97
TFC	**2.63**	**0.00**	**13.78**	**13.26**	**12.10**	**41.77**	**100.00**
INDUSTRY	**2.54**	**0.00**	**2.28**	**4.03**	**5.58**	**14.42**	**34.52**
Iron & Steel	1.91	0.00	0.01	0.18	0.36	2.46	5.39
Chemical	0.44	0.00	1.89	2.08	2.02	6.43	15.39
Non-ferrous	0.00	0.00	0.00	0.06	0.96	1.02	2.44
Non-metallic	0.09	0.00	0.10	0.37	0.25	0.81	1.94
Transp. Equipm.	0.00	0.00	0.01	0.05	0.08	0.14	0.34
Machinery	0.02	0.00	0.02	0.21	0.47	0.73	1.75
Textiles	0.00	0.00	0.07	0.00	0.10	0.18	0.43
Food Prod.	0.06	0.00	0.07	0.66	0.71	1.50	3.59
Paper, Pulp & Printing	0.00	0.00	0.00	0.27	0.47	0.75	1.80
Other	0.01	0.00	0.16	0.07	0.16	0.41	0.98
TRANSPORT	**0.00**	**0.00**	**9.65**	**0.00**	**0.21**	**9.86**	**23.61**
Air	0.00	0.00	1.55	0.00	0.00	1.55	3.71
Road	0.00	0.00	7.54	0.00	0.00	7.54	18.05
Rail	0.00	0.00	0.00	0.00	0.21	0.21	0.50
Other	0.00	0.00	0.56	0.00	0.00	0.56	1.34
OTHER	**0.09**	**0.00**	**1.85**	**9.23**	**6.32**	**17.50**	**41.90**
Agriculture	0.00	0.00	0.16	1.73	0.34	2.23	5.34
Commercia/Public	0.00	0.00	0.00	0.02	3.23	3.26	7.80
Residential	0.04	0.00	0.26	5.21	2.75	8.25	19.75
Other	0.06	0.00	1.43	2.27	0.00	3.76	9.00
Emission Factors: Mt carbon/Mtoe							
primary energy basis	1.11	0.89	0.84	0.64	—	—	—
delivered energy basis	1.15	0.89	0.98	0.66	2.06	—	—

Table A1.14

CARBON EMISSIONS, NEW ZEALAND (1988)

Mt carbon

	COAL	OTHER SOLIDS	OIL	GAS	ELECTRICITY	TOTAL	% OF TOTAL EMISSIONS
TPER	**1.32**	**0.41**	**2.79**	**2.07**	—	**6.59**	**100.00**
ELECTRICITY GENERATION	0.17	0.00	0.01	1.15	—	1.32	20.03
TFC	**1.15**	**0.41**	**2.78**	**0.93**	**1.32**	**6.59**	**100.00**
INDUSTRY	**1.04**	**0.28**	**0.21**	**0.69**	**0.57**	**2.80**	**42.49**
Iron & Steel	0.27	0.00	0.00	0.00	0.26	0.54	8.19
Chemical	0.00	0.00	0.00	0.30	0.03	0.33	5.01
Non-ferrous	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Non-metallic	0.00	0.00	0.00	0.00	0.01	0.01	0.15
Transp. Equipm.	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Machinery	0.00	0.00	0.00	0.00	0.02	0.02	0.30
Textiles	0.00	0.00	0.00	0.00	0.01	0.01	0.15
Food Prod.	0.00	0.00	0.03	0.00	0.08	0.11	1.67
Paper, Pulp & Printing	0.04	0.24	0.00	0.00	0.00	0.28	4.25
Other	0.73	0.05	0.17	0.39	0.16	1.49	22.61
TRANSPORT	**0.00**	**0.00**	**2.34**	**0.09**	**0.00**	**2.43**	**36.87**
Air	0.00	0.00	0.45	0.00	0.00	0.45	6.83
Road	0.00	0.00	1.42	0.09	0.00	1.51	22.91
Rail	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Other	0.00	0.00	0.47	0.00	0.00	0.47	7.13
OTHER	**0.11**	**0.12**	**0.24**	**0.15**	**0.75**	**1.37**	**20.79**
Agriculture	0.00	0.00	0.14	0.00	0.03	0.17	2.58
Commercial/Public	0.06	0.00	0.07	0.00	0.23	0.36	5.46
Residential	0.05	0.12	0.02	0.00	0.49	0.69	10.47
Other	0.00	0.00	0.01	0.15	0.00	0.16	2.43
Emission Factors: Mt carbon/Mtoe							
primary energy basis	1.10	0.89	0.84	0.64	—	—	—
delivered erergy basis	1.10	0.89	0.74[1]	0.97	0.59	—	—

1. Due to transformation of gas into 0.63 Mtoe cf synfuel.

Table A1.15
CARBON EMISSIONS, NORWAY (1988)
Mt carbon

	COAL	OTHER SOLIDS	OIL	GAS	ELECTRICITY	TOTAL	% OF TOTAL EMISSIONS
TPER	**1.10**	**0.82**	**5.37**	**1.14**	—	**8.43**	**100.00**
ELECTRICITY GENERATION	0.02	0.04	0.07	0.00	—	0.14	1.66
TFC	**1.09**	**0.78**	**5.30**	**0.00**[1]	**0.14**	**7.29**[1]	**86.48**
INDUSTRY	**1.07**	**0.36**	**0.99**	**0.00**	**0.07**	**2.48**	**29.42**
Iron & Steel	0.78	0.00	0.03	0.00	0.01	0.82	9.73
Chemical	0.12	0.00	0.12	0.00	0.01	0.25	2.97
Non-ferrous	0.02	0.00	0.08	0.00	0.03	0.12	1.42
Non-metallic	0.13	0.00	0.08	0.00	0.00	0.21	2.49
Transp. Equipm.	0.00	0.00	0.02	0.00	0.00	0.02	0.24
Machinery	0.00	0.00	0.05	0.00	0.00	0.05	0.59
Textiles	0.01	0.00	0.01	0.00	0.00	0.01	0.12
Food Prod.	0.01	0.00	0.16	0.00	0.00	0.17	2.02
Paper, Pulp & Printing	0.01	0.26	0.09	0.00	0.01	0.37	4.39
Other	0.00	0.09	0.36	0.00	0.00	0.46	5.46
TRANSPORT	**0.00**	**0.00**	**3.27**	**0.00**	**0.00**	**3.27**	**38.79**
Air	0.00	0.00	0.46	0.00	0.00	0.46	5.46
Road	0.00	0.00	2.17	0.00	0.00	2.17	25.74
Rail	0.00	0.00	0.02	0.00	0.00	0.03	0.36
Other	0.00	0.00	0.61	0.00	0.00	0.61	7.24
OTHER	**0.02**	**0.42**	**1.04**	**0.00**	**0.07**	**1.54**	**18.27**
Agriculture	0.01	0.00	0.17	0.00	0.00	0.18	2.14
Commercial/Public	0.00	0.02	0.38	0.00	0.02	0.42	4.98
Residential	0.01	0.40	0.49	0.00	0.04	0.95	11.27
Other	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Emission Factors: Mt carbon/Mtoe							
primary energy basis	1.11	0.89	0.84	0.64	—	—	—
delivered energy basis	1.18	0.89	0.83[2]	n.a.	0.02	—	—

1. No gas appears in TFC. TPER-related CO_2 emissions cannot be attributed to end-uses in industry, transport or other sectors of final consumption.
2. Due to a positive statistical difference of 0.32 Mtoe.

Table A1.16

CARBON EMISSIONS, PORTUGAL (1988)

Mt carbon

	COAL	OTHER SOLIDS	OIL	GAS	ELECTRICITY	TOTAL	% OF TOTAL EMISSIONS
TPER	**2.33**	**1.02**	**6.36**	**0.00**	—	**9.70**	**100.00**
ELECTRICITY GENERATION	1.53	0.13	0.75	0.00	—	2.40	24.74
TFC	**0.80**	**0.89**	**5.61**	**0.00**	**2.40**	**9.70**	**100.00**
INDUSTRY	**0.79**	**0.57**	**1.49**	**0.00**	**1.25**	**4.11**	**42.37**
Iron & Steel	0.21	0.00	0.03	0.00	0.06	0.30	3.09
Chemical	0.01	0.03	0.20	0.00	0.23	0.46	4.74
Non-ferrous	0.01	0.01	0.01	0.00	0.08	0.11	1.13
Non-metallic	0.57	0.27	0.30	0.00	0.17	1.31	13.51
Transp. Equipm.	0.00	0.00	0.02	0.00	0.02	0.04	0.41
Machinery	0.00	0.00	0.02	0.00	0.09	0.11	1.13
Textiles	0.00	0.06	0.25	0.00	0.22	0.53	5.46
Food Prod.	0.00	0.07	0.19	0.00	0.11	0.37	3.31
Paper, Pulp & Printing	0.00	0.11	0.23	0.00	0.15	0.48	4.95
Other	0.00	0.02	0.24	0.00	0.14	0.40	4.12
TRANSPORT	**0.00**	**0.00**	**3.08**	**0.00**	**0.03**	**3.11**	**32.06**
Air	0.00	0.00	0.50	0.00	0.00	0.50	5.15
Road	0.00	0.00	2.48	0.00	0.00	2.48	25.57
Rail	0.00	0.00	0.06	0.00	0.03	0.09	0.93
Other	0.00	0.00	0.05	0.00	0.00	0.05	0.52
OTHER	**0.00**	**0.32**	**1.04**	**0.00**	**1.12**	**2.48**	**25.57**
Agriculture	0.00	0.00	0.38	0.00	0.03	0.40	4.12
Commercial/Public	0.00	0.00	0.17	0.00	0.50	0.68	7.01
Residential	0.00	0.32	0.49	0.00	0.59	1.41	14.54
Other	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Emission Factors: Mt carbon/Mtoe							
primary energy basis	1.11	0.89	0.84	0.64	—	—	—
delivered energy basis	1.14	0.89	0.91	n.a	1.34	—	—

Table A1.17

CARBON EMISSIONS, SPAIN (1988)

Mt carbon

	COAL	OTHER SOLIDS	OIL	GAS	ELECTRICITY	TOTAL	% OF TOTAL EMISSIONS
TPER	**17.56**	**0.45**	**33.89**	**2.08**	—	**53.98**	**100.00**
ELECTRICITY GENERATION	12.28	0.14	1.76	0.12	—	14.30	26.49
TFC	**5.28**	**0.33**	**32.13**	**1.93**	**14.30**	**53.98**	**100.00**
INDUSTRY	**4.92**	**0.33**	**7.03**	**1.50**	**7.55**	**21.33**	**39.51**
Iron & Steel	2.64	0.00	0.40	0.17	1.19	4.39	8.13
Chemical	0.22	0.00	1.94	0.29	1.35	3.80	7.04
Non-ferrous	0.06	0.00	0.26	0.02	0.90	1.24	2.30
Non-metallic	1.82	0.00	2.03	0.46	0.71	5.03	9.32
Transp. Equipm.	0.00	0.00	0.11	0.08	0.33	0.51	0.94
Machinery	0.09	0.00	0.21	0.08	0.48	0.86	1.59
Textiles	0.00	0.00	0.25	0.13	0.42	0.80	1.48
Food Prod.	0.02	0.08	1.01	0.12	0.61	1.85	3.43
Paper, Pulp & Printing	0.04	0.25	0.38	0.12	0.52	1.31	2.43
Other	0.02	0.00	0.44	0.03	1.04	1.53	2.83
TRANSPORT	**0.00**	**0.00**	**19.12**	**0.00**	**0.38**	**19.50**	**36.12**
Air	0.00	0.00	2.36	0.00	0.00	2.36	4.37
Road	0.00	0.00	15.12	0.00	0.00	15.12	28.01
Rail	0.00	0.00	0.19	0.00	0.38	0.57	1.06
Other	0.00	0.00	1.45	0.00	0.00	1.45	2.69
OTHER	**0.36**	**0.00**	**5.99**	**0.44**	**6.36**	**13.14**	**24.34**
Agriculture	0.01	0.00	1.97	0.02	0.40	2.40	4.45
Commercial/Public	0.02	0.00	0.92	0.11	2.51	3.56	6.60
Residential	0.32	0.00	3.09	0.31	3.45	7.18	13.30
Other	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Emission Factors:							
Mt carbon/Mtoe							
primary energy basis	1.11	0.89	0.84	0.64	—	—	—
delivered energy basis	1.17	0.89	0.94	0.63[1]	1.46	—	—

1. Due to the transformation of coal into 0.14 Mtoe of gas.

Table A1.18

CARBON EMISSIONS, SWEDEN (1988)

Mt carbon

	COAL	OTHER SOLIDS	OIL	GAS	ELECTRICITY	TOTAL	% OF TOTAL EMISSIONS
TPER	**3.01**	**4.94**	**12.28**	**0.20**	—	**20.43**	**100.00**
ELECTRICITY GENERATION	1.12	0.34	0.42	0.00	—	1.88	9.20
TFC	**1.89**	**4.60**	**11.86**	**0.20**	**1.88**	**20.43**	**100.00**
INDUSTRY	**1.56**	**3.38**	**1.82**	**0.14**	**0.82**	**7.70**	**37.69**
Iron & Steel	0.90	0.00	0.30	0.00	0.08	1.28	6.27
Chemical	0.08	0.04	0.12	0.04	0.10	0.39	1.91
Non-ferrous	0.04	0.00	0.05	0.00	0.04	0.14	0.69
Non-metallic	0.31	0.00	0.19	0.00	0.02	0.52	2.55
Transp. Equipm.	0.02	0.00	0.03	0.00	0.04	0.10	0.49
Machinery	0.00	0.00	0.23	0.00	0.07	0.30	1.47
Textiles	0.00	0.00	0.04	0.00	0.01	0.05	0.24
Food Prod.	0.03	0.00	0.18	0.06	0.04	0.32	1.57
Paper, Pulp & Printing	0.09	2.78	0.45	0.00	0.03	3.62	17.72
Other	0.07	0.55	0.23	0.03	0.12	1.00	4.89
TRANSPORT	**0.00**	**0.00**	**6.41**	**0.00**	**0.04**	**6.45**	**31.57**
Air	0.00	0.00	0.69	0.00	0.00	0.69	3.38
Road	0.00	0.00	5.45	0.00	0.00	5.45	26.68
Rail	0.00	0.00	0.05	0.00	0.04	0.09	0.44
Other	0.00	0.00	0.21	0.00	0.00	0.21	1.03
OTHER	**0.33**	**1.23**	**3.63**	**0.06**	**1.03**	**6.28**	**30.74**
Agriculture	0.00	0.00	0.39	0.00	0.02	0.41	2.01
Commercial/Public	0.00	0.00	1.38	0.01	0.36	1.74	8.52
Residential	0.33	1.23	1.87	0.03	0.58	4.04	19.77
Other	0.00	0.00	0.00	0.02	0.07	0.09	0.44
Emission Factors:							
Mt carbon/Mtoe							
primary energy basis	1.11	0.89	0.84	0.64	—	—	—
delivered energy basis	1.18	0.89	0.86	0.75	0.17	—	—

Table A1.19

CARBON EMISSIONS, SWITZERLAND (1988)

Mt carbon

	COAL	OTHER SOLIDS	OIL	GAS	ELECTRICITY	TOTAL	% OF TOTAL EMISSIONS
TPER	**0.39**	**0.74**	**10.42**	**0.98**	—	**12.53**	**100.00**
ELECTRICITY GENERATION	0.01	0.35	0.09	0.02	—	0.47	3.75
TFC	**0.38**	**0.39**	**10.33**	**0.96**	**0.47**	**12.53**	**100.00**
INDUSTRY	**0.35**	**0.19**	**0.79**	**0.36**	**0.16**	**1.84**	**14.68**
Iron & Steel	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Chemical	0.00	0.05	0.12	0.16	0.02	0.36	2.87
Non-ferrous	0.00	0.00	0.01	0.02	0.02	0.05	0.40
Non-metallic	0.26	0.00	0.04	0.01	0.01	0.32	2.55
Transp. Equipm.	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Machinery	0.03	0.00	0.15	0.02	0.04	0.24	1.92
Textiles	0.00	0.00	0.05	0.01	0.01	0.07	0.56
Food Prod.	0.00	0.06	0.06	0.06	0.01	0.12	0.96
Paper, Pulp & Printing	0.02	0.06	0.11	0.06	0.02	0.26	2.08
Other	0.03	0.08	0.25	0.02	0.04	0.42	3.35
TRANSPORT	**0.00**	**0.00**	**4.59**	**0.00**	**0.03**	**4.61**	**36.79**
Air	0.00	0.00	0.90	0.00	0.00	0.90	7.18
Road	0.00	0.00	3.66	0.00	0.00	3.66	29.21
Rail	0.00	0.00	0.01	0.00	0.03	0.04	0.32
Other	0.00	0.00	0.01	0.00	0.00	0.01	0.08
OTHER	**0.03**	**0.20**	**4.95**	**0.61**	**0.29**	**6.07**	**48.44**
Agriculture	0.00	0.02	0.08	0.02	0.00	0.11	0.88
Commercial/Public	0.00	0.01	1.70	0.19	0.15	2.05	16.36
Residential	0.03	0.17	3.09	0.40	0.13	3.82	30.49
Other	0.00	0.00	0.09	0.00	0.00	0.09	0.72
Emission Factors: Mt carbon/Mtoe							
primary energy basis	1.11	0.89	0.84	0.64	—	—	—
delivered energy basis	1.11	0.89	0.82[1]	0.65	0.12	—	—

1. Due to a positive statistical difference of 0.43 Mtoe.

Table A1.20

CARBON EMISSIONS, TURKEY (1988)

Mt carbon

	COAL	OTHER SOLIDS	OIL	GAS	ELECTRICITY	TOTAL	% OF TOTAL EMISSIONS
TPER	**14.84**	**7.06**	**15.86**	**0.57**	—	**38.31**	**100.00**
ELECTRICITY GENERATION	4.26	0.00	0.89	0.52	—	5.67	14.80
TFC	**10.57**	**7.06**	**14.96**	**0.05**	**5.67**	**38.31**	**100.00**
INDUSTRY	**6.20**	**0.00**	**3.00**	**0.03**	**3.54**	**12.77**	**33.33**
Iron & Steel	2.23	0.00	0.44	0.00	0.60	3.27	8.54
Chemical	0.53	0.00	0.57	0.00	0.39	1.50	3.92
Non-ferrous	0.00	0.00	0.22	0.00	0.38	0.61	1.59
Non-metallic	0.01	0.00	0.00	0.03	0.55	0.58	1.51
Transp. Equipm.	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Machinery	0.03	0.00	0.01	0.00	0.13	0.18	0.47
Textiles	0.17	0.00	0.33	0.00	0.53	1.04	2.71
Food Prod.	0.52	0.00	0.00	0.00	0.40	0.92	2.40
Paper, Pulp & Printing	0.00	0.00	0.17	0.00	0.00	0.17	0.44
Other	2.70	0.00	1.26	0.00	0.55	4.51	11.77
TRANSPORT	**0.05**	**0.00**	**7.88**	**0.00**	**0.04**	**7.98**	**20.83**
Air	0.00	0.00	0.37	0.00	0.00	0.37	0.97
Road	0.00	0.00	7.06	0.00	0.00	7.06	18.43
Rail	0.05	0.00	0.25	0.00	0.04	0.34	0.89
Other	0.00	0.00	0.21	0.00	0.00	0.21	0.55
OTHER	**4.32**	**7.06**	**4.08**	**0.02**	**2.10**	**17.57**	**45.86**
Agriculture	0.00	0.00	1.64	0.00	0.06	1.71	4.46
Commercial/Public	0.00	0.00	0.00	0.00	0.92	0.92	2.40
Residential	4.32	7.06	2.43	0.02	1.08	14.91	38.92
Other	0.00	0.00	0.00	0.00	0.04	0.04	0.10
Emission Factors: Mt carbon/Mtoe							
primary energy basis	1.11	0.89	0.84	0.64	—	—	—
delivered energy basis	1.27	0.89	0.91	0.62[1]	1.75	—	—

1. Due to transformation of coal into 0.04 Mtoe of gas.

Table A1.21

CARBON EMISSIONS, UNITED KINGDOM (1988)

Mt carbon

	COAL	OTHER SOLIDS	OIL	GAS	ELECTRICITY	TOTAL	% OF TOTAL EMISSIONS
TPER	**73.31**	**0.00**	**58.24**	**29.58**	—	**161.12**	**100.00**
ELECTRICITY GENERATION	55.55	0.00	5.53	0.25	—	61.33	38.06
TFC	**17.76**	**0.00**	**52.71**	**29.33**	**61.33**	**161.12**	**100.00**
INDUSTRY	**10.74**	**0.00**	**7.36**	**8.42**	**22.04**	**48.56**	**30.14**
Iron & Steel	5.55	0.00	0.67	0.70	2.27	9.19	5.70
Chemical	1.06	0.00	1.29	2.34	4.33	9.02	5.60
Non-ferrous	0.13	0.00	0.08	0.25	1.50	1.96	1.22
Non-metallic	1.21	0.00	0.51	0.99	1.78	4.49	2.79
Transp. Equipm.	0.18	0.00	0.26	0.47	1.38	2.28	1.42
Machinery	0.11	0.00	0.59	1.08	3.21	4.99	3.10
Textiles	0.17	0.00	0.24	0.32	0.82	1.56	0.97
Food Prod	0.39	0.00	0.85	0.98	2.21	4.43	2.75
Paper, Pulp & Printing	0.45	0.00	0.26	0.52	1.61	2.83	1.76
Other	1.50	0.00	2.61	0.78	2.93	7.81	4.85
TRANSPORT	**0.00**	**0.00**	**38.74**	**0.00**	**0.76**	**39.49**	**24.51**
Air	0.00	0.00	5.97	0.00	0.00	5.97	3.71
Road	0.00	0.00	31.12	0.00	0.00	31.12	19.31
Rail	0.00	0.00	0.66	0.00	0.76	1.41	0.88
Other	0.00	0.00	0.99	0.00	0.00	0.99	0.61
OTHER	**7.02**	**0.00**	**6.62**	**20.91**	**38.53**	**73.07**	**45.35**
Agriculture	0.02	0.00	0.77	0.05	0.95	1.78	1.10
Commercial/Public	1.20	0.00	3.13	1.96	16.23	22.52	13.98
Residential	5.80	0.00	2.08	16.18	21.35	45.41	28.18
Other	0.00	0.00	0.64	2.72	0.00	3.36	2.09
Emission Factors: Mt carbon/Mtoe							
primary energy basis	1.11	0.89	0.84	0.64	—	—	—
delivered energy basis	1.17	n.a.	0.90	0.70	2.69	—	—

Table A1.22

CARBON EMISSIONS, UNITED STATES (1988)

Mt carbon

	COAL	OTHER SOLIDS	OIL	GAS	ELECTRICITY	TOTAL	% OF TOTAL EMISSIONS
TPER	**490.39**	**66.19**	**586.90**	**274.56**	—	**1 418.05**	**100.00**
ELECTRICITY GENERATION	418.97	0.41	31.76	46.31	—	497.45	35.08
TFC	**71.42**	**65.79**	**555.14**	**228.25**	**497.45**	**1 418.05**	**100.00**
INDUSTRY	**62.70**	**45.40**	**59.32**	**100.22**	**161.47**	**429.12**	**30.26**
Iron & Steel	23.10	n.a.	n.a.	n.a.	12.57	n.a.	n.a.
Chemical	11.70	n.a.	n.a.	n.a.	35.40	n.a.	n.a.
Non-ferrous	2.72	n.a.	n.a.	n.a.	17.23	n.a.	n.a.
Non-metallic	8.54	n.a.	n.a.	n.a.	6.82	n.a.	n.a.
Transp. Equipm.	1.14	n.a.	n.a.	n.a.	7.42	n.a.	n.a.
Machinery	1.44	n.a.	n.a.	n.a.	23.06	n.a.	n.a.
Textiles	0.99	n.a.	n.a.	n.a.	7.78	n.a.	n.a.
Food Prod.	4.12	n.a.	n.a.	n.a.	11.29	n.a.	n.a.
Paper, Pulp & Printing	7.68	n.a.	n.a.	n.a.	22.15	n.a.	n.a.
Other	1.26	n.a.	n.a.	n.a.	17.74	n.a.	n.a.
TRANSPORT	**0.00**	**0.00**	**424.86**	**0.00**	**0.80**	**425.66**	**30.02**
Air	0.00	0.00	63.92	0.00	0.00	63.92	4.51
Road	0.00	0.00	347.53	0.00	0.00	347.53	24.51
Rail	0.00	0.00	9.66	0.00	0.80	10.46	0.74
Other	0.00	0.00	3.74	0.00	0.00	3.74	0.26
OTHER	**8.72**	**20.38**	**70.95**	**128.04**	**335.18**	**563.27**	**39.72**
Agriculture	0.00	0.00	14.87	0.00	0.00	14.87	1.05
Commercial/Public	2.77	0.00	23.42	46.63	157.45	230.27	16.24
Residential	1.70	20.38	32.66	81.41	177.73	313.88	22.13
Other	4.25	0.00	0.00	0.00	0.00	4.25	0.30
Emission Factors: Mt carbon/Mtoe							
primary energy basis	1.08	0.89	0.84	0.64	—	—	—
delivered energy basis	1.10	0.89	0.88	0.75	2.32	—	—

ANNEX 2:
GLOSSARY OF TERMS AND ABBREVIATIONS

BAT	Best available technology.
BOF	Basic oxygen furnace.
BPM	Best practicable means.
Btu	British thermal unit.
CAFE	Corporate average fuel economy.
CC	Continuous casting.
CFC	Chlorofluorocarbons.
CFL	Compact fluorescent lighting.
CH_4	Methane.
CHP	Combined heat and power co-generation.
CNG	Compressed natural gas.
CO_2	Carbon dioxide.
CO	Carbon monoxide.
DRI	Direct reduction of iron.
DSM	Demand-side management.
EAF	Electric arc furnace.
ERC	Emission reduction credit.
FBC	Fluidised bed combustion.
FGD	Flue gas desulphurisation.
HC emissions	Emissions of unburnt hydrocarbons.
HDTV	High-definition television.
Hydrocarbons	Organic compounds consisting only of hydrogen and carbon.
IGCC	Integrated gasification combined cycle.
kgoe	kilogramme of oil equivalent
LNG	Liquefied natural gas (= methane).
LPG	Liquefied petroleum gas (= propane and butane).
MPG	Miles per gallon.
n.a.	not available
NO_x	Oxides of nitrogen.
O_3	Ozone.
Photochemical oxidants	Gaseous pollutants formed by the action of sunlight on nitrogen oxides and hydrocarbons in air.
PJ	Petajoule.
PM	Particulate matter.
R&D	Research, development and demonstration.
SCR	Selective catalytic reduction.
SFE	Supercritical fluids extraction.
SO_x	Sulphur oxides.

Synfuels	Fuels produced by a chemical synthesis process, such as those produced from the gasification or liquefaction of coal, or from the conversion of natural gas through methanol into gasoline.
TFC	Total final consumption.
TPER	Total primary energy requirements.
VOC	Volatile organic compounds, including hydrocarbon vapour emissions. Non-methane VOC emissions are made up essentially of highly volatile butane.
VMT	Vehicle-miles travelled.

ANNEX 3: REFERENCES AND SOURCES

Agence Française pour la Maîtrise de l'Energie [AFME] (1990). *Maîtrise de l'Energie.* Lettre Numéro 28. AFME, Paris.

Alonso, J.J. (1989). "The Ecomovil Programme of CADEM", in M. Roma (ed.), *Energy Efficiency in Land Transport.* Commission of the European Communities, Brussels.

Amann, C.A. (1989). "The Automotive Engine: A Future Perspective". Paper presented to the Society of Automotive Engineers, *Future Transportation Technology* conference held 8th-10th August 1989 in Vancouver, British Columbia.

American Council for an Energy Efficient Economy [ACEEE] (1987). *Acid Rain and Electricity Conservation.* ACEEE, Washington, DC.

Amols, G.R., K.B. Horward, A.K. Nicholls and T.D. Guerra (1988). *Residential and Commercial Buildings Data Book*, PNL-6454/UC-98. Pacific Northwest Laboratory, Richland, WA.

Association for the Conservation of Energy [ACE] (1988). *Contracts for Energy Management: A New Approach to Energy Efficiency.* OECD, Paris.

Australian Department of Primary Industries and Energy (1988). *Energy 2000: A National Policy Paper.* Government Publishing Service, Canberra, Australia.

Automobile Association (1990). *Motoring Costs for Petrol and Diesel Cars.* Automobile Association Technical Service, Basingstoke, UK.

Azimi, S.A. and H.L. Lowitt (1988). *The U.S. Steel Industry: An Energy Perspective.* DOE/RL/01830-T55. US Department of Energy, Washington, DC.

Berry, L. and E. Hirst (1990). "The U.S. DOE Least-Cost Utility Planning Program," *Energy.* (**15**: 12), pp. 1 107-1 117.

Bischoff, D. (1990). "Assessment of Future Potential Gains in Fuel Economy from Technology." Paper prepared for the IEA/OECD Rome *Workshop on Low Emission, Low Consumption Vehicles.* National Highway Traffic Safety Administration, Washington, DC.

Bleijenberg, A.N. and B.J. Rutten (1990). "Historical Trends and Technical Developments." Paper prepared for the IEA/OECD Rome *Workshop on Low Emission, Low Consumption Vehicles.* Centre for Energy Conservation and Environmental Technology, Delft, the Netherlands.

Bleviss, D.L. (1988). *The New Oil Crisis and Fuel Economy Technologies: Preparing the Light Transportation Industry for the 1990s.* Quorum Books, New York/London.

Blomen, L.J.M.J. (1989). "Fuel Cells: A review of fuel cell technology and its application," in T.B. Johansson, *et al.* (eds.), *Electricity: Efficient End-Use and New Generation Technologies, and Their Planning Implications.* Lund University Press, Lund, Sweden.

Blok, E., E. Worell, R.A.W. Albers and R.F.A. Cuelenaere (1990). *Data on Energy Conservation Techniques for the Netherlands.* Draft report. University of Utrecht, Utrecht, the Netherlands.

Bodlund, B., E. Mills, T. Karlsson and T.B. Johansson (1989). "The Challenge of Choices: Technology Options for the Swedish Electricity Sector," in T.B. Johansson, *et al.* (eds.), *Electricity: Efficient End-Use and New Generation Technologies, and Their Planning Implications.* Lund University Press, Lund, Sweden.

Boyle, S.T., and I. Brown (1989). "Reducing Greenhouse Gas Emissions: A Case Study of the Electricity, Building and Commercial/Industrial Sectors in the UK." In IEA/OECD, *Energy Technologies for Reducing Emissions of Greenhouse Gases*. OECD, Paris.

Bradely, J.D. (1990). "Taking the Heat out of the Sunlight: New Advances in Glazing Technology for Commercial Buildings." In the *Proceedings of the ACEEE 1990 Summer Study on Energy Efficiency in Buildings*. ACEEE, Washington, DC.

Brand, M. (1990). "Impacts of the structures of electricity and gas tariffs on the rational use of energy," *Energy Economics*. (**12**: 2), pp. 103-108.

Brookes, L. (1990). "The Greenhouse Effect: The Fallacies in the Energy Efficiency Solution," *Energy Policy*. (**12**, 2), pp. 199-201.

Bundesminister für Verkehr (1989). *Verkehr in Zahlen 1989*. Bonn.

Businaro, L. and A. Fedrighini (1981). "Prospects of Energy Conservation in Transportation," in F. Amman and R. Wilson (eds.), *Energy Demand and Efficient Use*. Plenum Press, New York/London.

Cambridge Energy Research Associates [CERA] (1990). *Lightening the Load: Electric Utilities and Demand Side Management*. Cambridge, MA.

Cartel Commission of Switzerland (1989). *Die Wettbewerbsverhältnisse auf dem Markt für Wärmeenergie*. Publications of the Swiss Cartel Commission and Price Surveillance, No. 2. Bern, Switzerland.

Centre for the Analysis and Dissemination of Demonstrated Energy Technologies [CADDET] (1988). *Catalogue of End-Use Technology Demonstration Projects in IEA Countries*. Sittard, the Netherlands.

Cheng, H.C., M. Steinberg and M. Beller (1986). *Effects of Energy Technology on Global CO_2 Emissions*. DOE/NBB-0076. US Department of Energy, Washington, DC.

Cheslow, G. (1984). *Value of Automobile Attributes to Consumers*. For the US Department of Energy. MITRE, Washington, DC.

Cicchetti, C.J. and W. Hogan (1989). "Including Unbundled Demand-side Options in Electric Utility Bidding Programs," *Public Utilities Fortnightly*, 8th June 1989, pp. 9-20.

Commission of the European Communities [EEC], Directorate General for Energy (1990). *Energy in Europe. Energy for a New Century: The European Perspective*. Special Issue, July 1990. EEC, Brussels.

Danish Energy Agency (1990). *Energiforbrug i bygninger: Baggrundsrapport nr. 1 til ENERGI 2000*. Copenhagen.

Danish Ministry of Energy (1990). *Energy 2000: A Plan of Action for Sustainable Development*, Copenhagen.

Danish Ministry of Transport (1991). *The Danish Transport Action Plan for Environment and Development*, Copenhagen.

Davidson, W.F. and E.L. Erickson (1987). "260° C Absorption Heat Pumping Now Possible," *Energy Technology XIV: Changing Times for Energy Industries*. Government Institutes, Inc., Washington, DC.

Davis, C., Deborah B. Shonka, Gloria J. Anderson-Batiste, Patricia S. Hu (1989). *Transportation Energy Data Book: Edition 10*. Oak Ridge National Laboratory. Oak Ridge, TN.

Davis, G.R. (1990). "Energy for Planet Earth," *Scientific American*. September, pp. 21-27.

Delsey, J. (1990). "How to Reduce Fuel Consumption." Paper prepared for the IEA/OECD Rome *Workshop on Low Emission, Low Consumption Vehicles*. Institut National sur l'Energie et les Transports, Bron, France.

Denison, E.F. (1985). *Trends in American Economic Growth, 1929-1982*. The Brookings Institution, Washington, DC.

Dennerlein, R.K.H., G. Flaig, F. Carlevaro, I. Krishnakumar and C. Spierer (1987). *Stromverbrauchsverhalten privater Haushalte, Expertengruppe Energieszenarien (EGES)*. No. 13, Eidgenössische Drucksachen- und Materialzentrale, Bern, Switzerland.

Dennerlein, K.-H. (1990). *Energieverbrauch privater Haushalte*. Maro-Verlag, Augsburg, Germany.

Depretz, H. and P. Michel (1990). "Improving Domestic Electric Appliances: The French Ways." In the *Proceedings of the ACEEE 1990 Summer Study on Energy Efficiency in Buildings*. ACEEE. Washington, DC.

Difiglio, C., K.G. Duleep and D.L. Greene (1990). "Cost Effectiveness of Future Fuel Economy Improvements," *The Energy Journal*. (**11**: 1), pp. 65-86.

Data Resources, Inc. [DRI], European Energy Service (1989). *European Transport Energy Consumption*. DRI, Paris.

Data Resources, Inc. [DRI] (1990). *What Public Policy Can Do to Influence Carbon Dioxide Emissions from the US Transportation Sector: A Preliminary Statement of Findings*. For US Environmental Protection Agency, Washington, DC.

Economist Intelligence Unit (The) (1989). *The Car of the Future in Western Europe*. The Economist Intelligence Unit, London.

Edmonds, J.A. and D.W. Barnes (1990). *Estimating the Marginal Cost of Reducing Global Fossil Fuel CO_2 Emissions*. PNL-SA-18361. Pacific Northwest Laboratory, Richland, WA.

Electric Power Research Institute [EPRI] (1988a). *Electrotechnology Reference Guide: Revision 1*. EPRI EM-4527. Palo Alto, CA.

Electric Power Research Institute [EPRI] (1988b). *TAG™ Technical Assessment Guide: Industrial Electricity Use — 1987*. EPRI P-4463-SR, Volume 2, Part 3. Palo Alto, CA.

Electric Power Research Institute [EPRI] (1990). *Efficient Electricity Use: Estimates of Maximum Energy Savings*. EPRI CU-6746. Palo Alto, CA.

Energy Conservation Center (The) (1989). *Energy Conservation in Japan: 1989*. The Energy Conservation Center, Tokyo.

Energy Conservation Center (The) (1990). *'89 Successful Cases of Energy Conservation*. The Energy Conservation Center, Tokyo.

Energy Efficiency Office [EEO] (1984). *Energy Use and Energy Efficiency in UK Manufacturing Industry up to year 2000*. Energy Efficiency Series, No. 3. Her Majesty's Stationery Office, London.

Energy Efficiency Office [EEO] (1988). *Energy Use and Energy Efficiency in UK Commercial and Public Buildings up to year 2000*. Energy Efficiency Series, No. 6. Her Majesty's Stationery Office, London.

Energy Efficiency Office [EEO] (1989). *Energy Use and Energy Efficiency in UK Transport up to the Year 2010.* Energy Efficiency Series, No. 10. Her Majesty's Stationery Office, London.

Energy Efficiency Office [EEO] (1990). *Energy Efficiency in Domestic Electric Appliances.* Energy Efficiency Series, No 13. Her Majesty's Stationery Office, London.

European Conference of Ministers of Transport [ECMT] (1989). *Ministerial Session on Transport and the Environment: Background Reports.* ECMT, Paris.

Federal Highway Administration [FHWA] (1988). *America's Challenge for Highway Transportation in the 21st Century.* FHWA, Washington, DC.

Feist, W. (1987). *Niedrig-Energiehäuser in Dänemark und Schweden.* IWU, Darmstadt, Germany.

Ferguson, M. and C. Holman (1990). *Atmospheric Emissions from the Use of Transport in the United Kingdom, Volume 2: The Effect of Alternative Transport Policies.* Earth Resources Research, World Wildlife Fund, London.

Fickett, A.P., C.W. Gellings and A.B. Lovins (1990). "Efficient Use of Electricity," *Scientific American.* September, pp. 29-36.

French, D. (1990). *Review of industrial technologies.* USDOE Memo, 6th March 1990, Washington, DC.

Fulkerson, W., D.B. Reister and J.T. Miller (eds.) (1989a). "End-Use Technology," in *Energy Technology R&D: What Could Make a Difference?* ORNL-6541/V2/P1. Oak Ridge National Laboratory, Oak Ridge, TN.

Fulkerson, W., D.B. Reister and J.T. Miller (eds.) (1989b). "Crosscutting Science and Technology," in *Energy Technology R&D: What Could Make a Difference?* ORNL-6541/V2/P3. Oak Ridge National Laboratory. Oak Ridge, TN.

Fuller, K.E. (1990). "NORDAX: Value of the Database," *Conference proceedings, Enhancing Electricity's Value to Society*, Vol. 1, Canadian Electrical Association, Toronto.

Garrett-Price, B.A. (1985). *Potential for Energy Conservation in the Cement Industry.* PNL-5330. Pacific Northwest Laboratory, Richland, WA.

Garrett-Price, B.A., A.G. Fassbender, and G.A. Bruno (1986). *Potential for Energy Conservation in the Glass Industry.* PNL-5640. Pacific Northwest Laboratory, Richland, WA.

Garrett-Price, B.A., L.L. Fassbender, E.J. Westergard and E.A. Griffin (1987). *Potential for Energy Conservation in the Pulp and Paper Industry.* PNL-5996. Pacific Northwest Laboratory, Richland, WA.

Gelineau, J.-M. (1990). "L'induction en cuisson domestique," *Revue de l'energie*, 41e année, No. 424, October, pp. 489-491.

Gellings, C.W., V.A. Rabl and J.H. Chamberlin (1990). "Demand-Side Management: The Winds of Change," *Conference proceedings, Enhancing Electricity's Value to Society*, Vol. 1, Canadian Electrical Association, Toronto.

Giovannini, B. and D. Pain (1990). *Scientific and Technical Arguments for the Optimal Use of Energy.* University of Geneva, Geneva, Switzerland.

Goldman, C., E. Hirst and F. Krause (1989). *Least-Cost Planning in the Utility Sector: Progress and Challenges.* LBL-27130, ORNL/CON-284. Oak Ridge National Laboratory, Oak Ridge, TN.

Grandqvist, C.G. (1989). "Energy-Efficient Windows: Options with Present and Forthcoming Technologies," in T.B. Johansson, *et al.* (eds.), *Electricity: Efficient End-Use and New Generation Technologies, and Their Planning*

Greene, D.L. (1990). "CAFE or Price?: An Analysis of the Effects of Federal Fuel Economy Regulations and Gasoline Price on New Car MPG, 1978-89," *The Energy Journal.* (**11**: 3), pp. 37-57.

Greenhalgh, G. (1990). "Energy conservation policies," *Energy Policy.* (**18**: 3), pp. 293-299.

Grubb, M.J. (1989). *The Greenhouse Effect: Negotiating Targets.* Royal Institute for International Affairs, London.

Grubb, M.J. (1990). "Energy efficiency and economic fallacies," *Energy Policy.* (**18**: 8), pp. 783-785.

Haites, E. (1991). "Canada: Opportunities for Carbon Emissions Control." Forthcoming in *Carbon Emissions Control Strategies: Case Studies in International Cooperation.*

Hartmann, R.S. and M.J. Doane (1986). "Household Discount Rates Revisited," *The Energy Journal.* (**7**: 1), pp. 139-148.

Hausman, J.A. (1979). "Individual Discount Rates and the Purchase and Utilisation of Energy-Using Durables," in *The Bell Journal of Economics.* (**10**: 1), pp. 33-54.

Heidell, J.A. and M.J. King (1990). "The Industrial Sector: A Conservation Gold Mine or a Quagmire?" *Proceedings of the ACEEE 1990 Summer Study on Energy Efficiency in Buildings.* Volume 8. ACEEE, Washington, DC.

Henderson, G. and L. Shorrock (1990). "Carbon Dioxide Emissions and Energy Efficiency in Existing UK Buildings" *Proceedings of the ACEEE 1990 Summer Study on Energy Efficiency in Buildings.* ACEEE, Washington, DC.

Herppich, W., Zuchtriegel, T., Schulz, W. (1989). *Least-Cost Planning in den USA*, R. Oldenbourg Verlag, Munich.

Hillsman, E.L. and F. Southworth (1990). *Factors That May Influence Responses of the US Transportation Sector to Policies for Reducing Greenhouse Gas Emissions.* ORNL-TH 37831-6206. Oak Ridge National Laboratory, Oak Ridge, TN.

Höller, P., A. Dean and J. Nicolaisen (1990). *A Survey of Studies of the Costs of Reducing Greenhouse Gas Emissions.* Working Paper No 89. OECD, Paris.

Hoen, M.R. and B.R. Kennedy (1988). *Compilation and Analysis of Canada Energy Audit Program Data, Manufacturing Industries.* Ministry of Energy, Mines and Resources, Ottawa.

Inquiry Commission (1990). *Vorsorge zum Schutz der Erdatmosphäre.* Dritter Bericht, Deutsche Bundestag, Bonn.

Institut für Wohnen und Umwelt [IWU] (1989). *Stromverbrauch im Haushalt - Einsparpotentiale, Wirtschafltichkeit und zukünftige Entwicklungsmöglichkeiten.* IWU, Darmstadt, Germany.

International Energy Agency [IEA] (1987). *Energy Conservation in IEA Countries.* OECD, Paris.

International Energy Agency [IEA] (1988a). *Catalogue of End-Use Technology Demonstration Projects in IEA Countries [CADDET] Newsletter.* OECD, Paris.

International Energy Agency [IEA] (1988b). *Emission Controls in Electricity Generation and in Industry.* OECD, Paris.

International Energy Agency [IEA] (1989). *Electricity End-Use Efficiency.* OECD, Paris.

International Energy Agency [IEA] (1990a). *Energy Balances of OECD Countries.* OECD, Paris.

International Energy Agency [IEA] (1990b). *Energy Prices and Taxes.* OECD, Paris.

International Energy Agency [IEA] (1990c). *Energy and the Environment: Policy Overview.* OECD, Paris.

International Energy Agency [IEA] (1990d). *Energy Policies and Programmes of IEA Countries: 1989 Review.* OECD, Paris.

International Energy Agency [IEA] (1991a). *Fuel Efficiency of Passenger Cars.* OECD, Paris.

International Energy Agency [IEA] (1991b). *Energy Policies of IEA Countries: 1990 Review.* OECD, Paris.

International Energy Agency [IEA] and the Organisation for Economic Co-operation and Development [OECD] (1991). *Greenhouse Gas Emissions: The Energy Dimension.* OECD, Paris.

International Iron and Steel Institute (1990). *Statistics on Energy in the Steel Industry (1990 Update).* Committee on Statistics, Brussels.

International Road Federation [IRF] (1989). *World Road Statistics.* IRF, Geneva/Washington, DC.

Jochem, E. and T. Morovic (1988). "Energy Use Patterns in Common Market Countries Since 1979," *Annual Review of Energy*, (**13**), pp. 131-157.

Johansson, T.B., B. Bodlund and R.H. Willians (eds.) (1989). *Electricity: Efficient End-Use and New Generation Technologies, and Their Planning Implications.* Lund University Press, Lund, Sweden.

Johansson, T.B. and R.H. Williams (1987). "Energy Conservation in the Global Context," *Energy*, (**12**. 10/11), pp. 902-915.

Jorgenson, D.W. and P.J. Wilcoxen (1989). "Environmental Regulation and US Economic Growth," *The Rand Journal of Economics*, (**21**: 2).

Koga, K. and H. Wakasa (1990). "Present Residential Energy Consumption and its Future," *Energy in Japan*, (**106**), pp. 48-64.

Kolbe, A.L. and M.P. O'Loughlin (1990). "Evaluation of Demand Side Management Programmes," *Conference proceedings, Enhancing Electricity's Value to Society*, Vol. 1, Canadian Electrical Association, Toronto.

Lesch, K.-H., (1990). *Energiesparpotentiale für Österreich. Technischer Zwischenbericht, Teilbereich Elektrische Energie.* Österreichische Gesellschaft für Ökologie, Vienna.

Lovins, A.B. and R. Sardinsky (1988). *The State of the Art: Lighting.* Rocky Mountain Institute, Snowmass, CO.

Lovins, A.B. (1989). *The State of the Art: Drivepower.* Rocky Mountain Institute, Snowmass, CO.

March Consulting Group (1988). *The Effective Marketing of Improvements in the Efficiency of Electricity Use.* For the Commission of the European Communities, Contract No. 88-B-7010-11-2-17.

Manne, A.S. and R.G. Richels (1990). *Global CO_2 Emission Reductions: the Impact of Rising Energy Costs.* Electric Power Research Institute, Palo Alto, CA.

Marbek Resource Consultants Ltd. (1986). *Energy Efficient Fluorescent Lighting in Canadian Office Buildings: Technologies, Market Factors and Penetration Rates.* Marbek, Ottawa.

McInnes, G. and E. Unterwurzacher (1991). "Electricity End-Use Efficiency: An Assessment of the Scope for Efficiency Gains and of Policy Options," *Energy Policy* (**19**: 3), pp. 208-216.

Meier, A.K. and J. Whittier (1983). "Consumer discount rates implied by consumer purchases of energy-efficient refrigerators," *Energy: The International Journal*. (**8**: 12), pp. 957-962.

Meier, A., J. Wright and A.H. Rosenfeld (1983). *Supplying Energy Through Greater Efficiency*. University of California Press, Berkeley, CA.

Mellde, R. (1990). *Volco LCP 2000 Light Component Project*. Paper No 850570. Society of Automotive Engineers, Warrendale, PA.

Mills, E. (1989). *An End-Use Perspective on Electricity Price Responsiveness*. Uppdrag 2000 Project. Vattenfall, Stockholm.

Mills, E. (1991a). "Evaluation of European Lighting Programmes: Utilities Finance Energy Efficiency," *Energy Policy*, (**19**: 3), pp. 266-278.

Mills, E., D. Wilson and T.B. Johansson (1991b). "Getting Started: No-Regrets Strategies for Reducing Greenhouse-Gas Emissions," forthcoming in *Energy Policy*.

Ministry of International Trade and Industry [MITI] (1986). *The 21st Century Energy Vision*. Tokyo.

Ministry of International Trade and Industry [MITI] (1990). *Advisory Committee for Energy, Summary of Report*. Tokyo.

Moore, J., L. Parker, J. Blodgett, J. McCarthy and D. Gushee (1989). *Using Incentives for Environmental Protection: An Overview*. Congressional Research Service. The Library of Congress, Washington, DC.

Netherlands Minister of Economic Affairs (1990). *Memorandum on Energy Conservation: Strategy for energy conservation and renewable energy resources*. Presented to the Second Chamber of the States General. The Hague.

Neumann, K.-H. (1989). "Energy Efficiency Improvement as a Tool for Influencing Future Engine Technology," in M. Roma (ed.), *Energy Efficiency in Land Transport*. Commission of the European Communities, Brussels.

Nordhaus, W.D. (1990). *To Slow or Not to Slow: The Economics of the Greenhouse Effect*. (Mimeographed) Yale University, New Haven, CN.

Norford, L., J.P. Harris, A. Rabl and J. Roturier (1989). "Electronic Office Equipment: The Impact of Market Trends and Technology on End-Use Demand for Electricity." In T.B. Johansson, *et al*. (eds.), *Electricity: Efficient End-Use and New Generation Technologies, and Their Planning Implications*. Lund University Press, Lund, Sweden.

Oak Ridge National Laboratory [ORNL] (1990). Principal authors: R.S. Carlsmith, W.U. Chandler, J.E. McMahon and D.J. Santini. *Energy Efficiency: How Far Can We Go?* ORNL/TM/11441. Oak Ridge, TN.

Office of Technology Assessment [OTA] (1983). *Industrial Energy Use*. US Congress. US. Government Printing Office, Washington, DC.

Office of Technology Assessment [OTA] (1990). *Energy Use and the US Economy*. US Congress. US Government Printing Office, Washington, DC.

Organisation for Economic Co-operation and Development [OECD] (1982). *Automobile Fuel Consumption in Actual Traffic Conditions*. OECD, Paris.

Organisation for Economic Co-operation and Development [OECD] (1983a). *Aluminium Industry: Energy Aspects of Structural Change.* OECD, Paris.

Organisation for Economic Co-operation and Development [OECD] (1987). *Energy and Cleaner Air: Cost of Reducing Emissions.* Summary and Analysis of Symposium Enclair'86. OECD, Paris.

Organisation for Economic Co-operation and Development [OECD] (1988). *Transport and the Environment.* OECD, Paris.

Organisation for Economic Co-operation and Development [OECD] (1989a). *The Iron and Steel Industry in 1988.* OECD, Paris.

Organisation for Economic Co-operation and Development [OECD] (1989b). *OECD Environmental Data: Compendium 1989.* OECD, Paris.

Organisation for Economic Co-operation and Development [OECD] (1990). *Historical Statistics 1960-1987.* OECD, Paris.

Organisation for Economic Co-operation and Development [OECD] (1991). *Climate Change: Evaluating Socio-Economic Impacts.* OECD, Paris.

Potter, S. (1990). *The Sierra Set Rolls On.* Energy and Environment Research Unit Working Paper. The Open University, Milton Keynes, UK.

Redsell, R. (1988). *Comparison of On-Road Fuel Consumption for Diesel and Petrol Cars.* Transport Road Research Laboratory. Contractor report number 79. Crowthorne, UK.

Regio-Tec Gmbh Starnberg (1990). *Analysis of the Ecological Impact of Demonstration Projects in the Field of Rational Use of Energy: Development of Evaluation Criteria.* Study on behalf of the Commission of the European Communities, Brussels.

Robinson, J.B. (1990). "Decarbonating Energy Systems: The Potential for Reducing CO_2 Emissions Through Reduced Energy Intensity in Canada," *Energy Studies Review.* (**2**: 1).

Rosenberg, N. and L.E. Birdzell, Jr. (1990). "Science, Technology, and the Western Miracle," *Scientific American.* November, pp. 18-25.

Ross, M.H. and D. Steinmeyer (1990). "Energy for Industry," *Scientific American.* September, pp. 47-53.

Ruderman, H., M.D. Levine, J. McMahon, I. Turiel and S. Stoft (1990). "Impacts of Federal Efficiency Standards for Residential Appliances," in *Proceedings of the Seminar on Energy Conservation Policies and Technologies for Buildings in Egypt.* Vol. 1, Organisation for Energy Planning, Egypt, and Lawrence Berkeley Laboratory, Berkeley, CA.

RWE-Energie (1990). *Market Information for Major Residential Appliances.* RWE, Essen, Germany.

Santini, Danilo (1985). *Direct and Indirect Costs Arising from Implementation of New Engines.* Argonne National Laboratory, Argonne, IL.

Schaefer, H. (1988). "Ways and techniques in the rational use of energy," in J. Sirchis (ed.), *Energy Efficiency in Industry.* Elsevier Applied Science, London.

Schipper, L. (1988). *Household Electricity Use in Six IEA Countries.* Lawrence Berkeley Laboratory, University of California, Berkeley, CA.

Schipper, L. and S. Tyler (1990). "The dynamics of electricity use in Scandinavian households," *Energy: The International Journal*. (**15**: 10).

Skinner, Robert (1990). "Energy Conservation: Overview of Experiences in IEA Countries," in *Proceedings of the Seminar on Energy in East and West: The Polish Case*. OECD, Paris.

Southern California Edison [SCE] (1986). *1987 Energy Management Plan*. SCE, Los Angeles, CA.

Strack, J.T. (1987). "Heat Pumps in Drying Applications in Canada," *Energy Technology XIV: Changing Times for Energy Industries*. Government Institutes, Inc., Washington, DC.

Tardieu, Ph. (1989). "A European View." In *Energy Efficiency in Land Transport*. Proceedings of a seminar organised by the Commission for the European Communities, Brussels.

TNO Netherlands Organisation for Applied Scientific Research (1990). *Energy Conservation Potentials 2015*. Report for the Directorate General for Energy, Ministry of Economic Affairs. Apeldoorn, the Netherlands.

Untermark. D. (1989). "Least-Cost Planning in US-amerikanischen Elektrizitätsversorgungsunternehmen." in *Zeitschrif für Energiewirtschaft*, Vol. 2, pp. 129-135.

US Department of Energy [USDOE] (1983). *Industrial Energy Productivity Project: Final Report*. Vol. 8, Overall Study Methodology. DOE/CS/40151-1. US Government Printing Office, Washington, DC.

US Department of Energy [USDOE] (1987). *Energy Security: A Report to the President of the United States*. Appendix E: Analysis of the Effects of a Gasoline Tax. DOE/S-0057. Washington, DC.

US Department of Energy [USDOE] (1988). *Technical Support Document: Energy Conservation Standards for Consumer Products*. Assistant Secretary, Conservation and Renewable Energy, Building Equipment Division. Report DOE/CE-0239. Washington, DC.

US Department of Energy [USDOE] (1990a). *National Energy Strategy Reference/Conservation/High Conservation Cases*. (Mimeographed.) Washington, DC.

US Department of Energy [USDOE] Energy Information Administration (1990b). *Annual Energy Review 1989*. DOE/EIA-0384(89). Washington, DC.

US Department of Energy [USDOE] Energy Information Administration. (1990c). *Manufacturing Energy Consumption Survey: Changes in Energy Efficiency 1980-1985*. DOE/EIA-0516(85). Washington, DC.

US Department of Energy [USDOE]. (1991). *National Energy Strategy*. First edition, 1991/1992. US Government Printing Office, Washington, DC.

US Environmental Protection Agency [EPA] (1989). *Policy Options for Stabilising Global Climate*. Draft Report to Congress. Washington, DC.

Vine, E.L. and J.P. Harris (1990). "Evaluating Energy and Non-Energy Impacts of Energy Conservation Programs: A Supply Curve Framework of Analysis," *Energy: The International Journal*. (**15**: 1), pp. 11-21.

Von Hippel, F. (1987). "Automobile Fuel Economy," *Energy*. (**12**: 10/11).

Von Hippel, F. and B. Levi (1983). "Automobile Fuel Efficiency: The Opportunity and Weakness of Existing Market Incentives," *Resources and Conservation*. (**10**: 1983), pp. 103-124.

Whalley, J. and R. Wigle (1990). "The International Incidence of Carbon Taxes," paper presented at a conference on *Economic Policy Responses to Global Warming*, Rome.

Wilfert, G.L., S. Kolar and W.U. Chandler (1990). *Industrial Energy Efficiency Supply Curves: Methodology and Selected Technology Descriptions*. Draft Report. Pacific Northwest Laboratory, Richland, WA.

Williams, R.L., E.D. Larson and M. Ross (1987). "Materials, Affluence and Industrial Energy Use," in *Annual Review of Energy*, (**12**), pp. 99-144.

Zentralverband Elektrotechnik und Elektroindustrie E.V. [ZVEI] (1989). *Entwicklung des Stromverbrauchs von Elektro-Hausgeräten: Energeteinsparung 1985-1988*. ZVEI, Frankfurt.

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