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# Using Scenarios to Explore Future Energy Demand in Industrialized Countries

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# Using Scenarios to Explore Future Energy Demand in Industrialized Countries

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## ABSTRACT

We present three scenarios of OECD-average sectoral energy intensities in the year 2010. These represent (1) where current and expected trends seem to be pointing, (2) what might occur if improving energy efficiency were given a high priority by governments and the private sector, and (3) what might be achieved if restraining energy use was recognized as a very high priority for public policy (such as might occur if emissions were recognized as a very serious problem). The scenarios delineate an important (if somewhat vague) boundary between a relatively easily attainable improvement in efficiency and a more problematic level of change. With a mixture of pricing and other policies, they suggest that OECD primary energy use in 2010 could be 20-25% less than where trends are pointing (or about equal to demand in 1989) if fairly strong efforts are made. To increase that reduction to 40-45% would be very challenging, but does not seem impossible.

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## 1. Introduction

The question of how much energy could be saved in the industrialized (OECD) countries through improved energy efficiency has been the subject of many studies and considerable debate. In recent years, as concern over carbon dioxide ($CO_2$) emissions from fossil fuel use has mounted, the number of such studies has grown almost beyond the capacity of researchers and policy analysts to keep up with them — or at least review them carefully. And careful review is needed, because studies differ considerably in their methods, assumptions, degree of disaggregation, quality of data, and of course, their conclusions.

Many studies have looked rather carefully at the technical potential for improving energy efficiency in different end uses, and have developed reasonable (if not definitive) estimates of today's incremental costs of higher efficiency.[1] A common way to describe the overall energy efficiency potential is to estimate the reduction in energy use that could be achieved in each end use if the best available or potentially-available technology and techniques were fully penetrated across the existing capital stock. While useful, this method is somewhat unsatisfying because it does not reflect the dynamics of the real world, in which the stock is evolving and the roles of different end uses are changing. Expressing the future potential more realistically requires estimating how the capital stock and structure of energy use will evolve. Against this backdrop of estimated trends, the analyst may then project one or more levels of market adoption of higher energy efficiency. The analyst may simply assume that certain technologies will penetrate to a certain degree (to show an example), or may try to connect particular levels of penetration with changes in energy prices or energy-efficiency policies.

In this paper, we describe an exercise in which we adopted the latter approach to construct a plausible portrait of how OECD energy intensities seem to be evolving over the next 20 years, and then show how that might be different given changed 'boundary conditions' with respect to energy prices and efficiency policies. The three scenarios represent an 'informed judgement' of (1) where current and expected trends seem to be pointing, (2) what might occur if improving energy efficiency were given a high priority by governments and the private sector, and (3) what might be achieved if restraining energy use was recognized as a very high priority for public policy (such as might occur if $CO_2$ emissions were recognized as a very serious problem).

## 2. Basis for the Scenarios

What makes these scenarios somewhat unique is that they draw on a detailed sectoral data base covering the 1970-1988 period (1989 in some cases) that we have developed for the US, Japan, and seven European countries (West Germany, France, the UK, Italy, Sweden, Norway, and Denmark).[2] They are built from patterns of energy use in 1985 for approximately 25 different end uses. We assume that the energy end-use pattern estimated for the average of these nine countries applies to the entire OECD. Since the nine countries account for about 85% of total OECD energy use, this is a reasonable assumption. The values are expressed for the OECD-average, but in many cases are based on separate considerations of the US, Japan, and Western Europe. Since the US accounts for nearly half (or more) of total

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[1] See, for example: R. Carlsmith, *et al, Energy Efficiency: How Far Can We Go?* Oak Ridge National Laboratory, Oak Ridge, Tenn., USA, 1990; Enquete-Kommission, *Energieeinsparung sowie rationelle Energienutzung und umwandlung,* Economica Verlag, Bonn, Germany, 1990.

[2] The data on sectoral energy use in the OECD countries have been published in numerous articles and reports. They have recently been updated and placed in a common framework in L. Schipper and S. Meyers, with R. Howarth and R. Steiner, *Energy Efficiency and Human Activity: Past Trends, Future Prospects,* Cambridge University Press, Cambridge, UK, 1992.

OECD energy use in each sector, trends there play a major role in the OECD average.

The scenarios are grounded in our analyses of historical trends.[3] Understanding recent trends is necessary for projecting where things are heading over the next 5-10 years. This is not to say that the determining forces will be at work in the same manner in the 1990s as in the 1980s. But in many areas the trends that have been in motion exert a strong momentum, especially since it seems unlikely that there will be significant change in energy prices (absent a major policy shift). Further, the experience of the past sheds light on the rates of change that have occurred in specific historical circumstances. The 1970-1988 period includes years in which energy prices rose considerably and energy-saving policies were widely implemented. The record in these periods provides insight into what might occur in the future, given a particular energy price and policy environment. Indeed, as we discuss further, the rates of change assumed in the scenarios were based in part on the rates that occurred in specific periods in the past.

A discussion of past trends in OECD sectoral energy use is beyond the scope of this paper. Wherever possible, however, we do describe the changes that occurred in the various OECD-average values in the 1972-1985 period in order to give the reader an understanding of how the 1985-2010 period in the scenarios compares with that historic period.

Since the base year for the scenarios is 1985, actual trends in the 1986-1988 period were used as a 'jumping-off point' for the scenarios. Thus, the values for the 1985-2010 period take account of actual trends in the late 1980s as well as our visions of the future. In most cases, there has been much slower decline in energy intensities since 1985 (or even no decline at all) than in the preceding decade.

While past trends play an important role, the values in the scenarios are also influenced by the energy intensities of *new* systems in the late 1980s, our consideration of future prospects and reachable potentials for new systems, and our assessment of how rapidly new systems may be incorporated into the stock. The consideration of prospects for intensities, while obviously subjective, is based on our reading of the 'efficiency potential' literature in the OECD countries.[4]

## 3. Analytical Framework

In constructing the scenarios, we adopt the same analytical framework used in our examination of historical trends. We consider five major end-use sectors: manufacturing, passenger travel, freight transportation, residential, and services (often called the 'commercial' sector). (We have not analyzed energy use in agriculture, mining, and construction, as energy-use data for these sectors are often uncertain. These sectors account for only about 10% of total OECD final energy use.) We disaggregate each sector into subsectors or end uses. Within each sector, we consider three basic elements that shape energy use: activity, structural change, and subsectoral energy intensities.

We measure *activity* in terms of real value added (VA) in manufacturing and services (with local currency values converted to US dollars based on purchasing power parities). We use passenger-km (p-km) and tonne-km (t-km) for travel and freight transport. We use population for the residential sector.[5]

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[3] Analysis of trends in sectoral energy use in the OECD countries by the authors and their colleagues at Lawrence Berkeley Laboratory has been published in numerous articles and reports. For a recent comprehensive discussion, see Schipper and Meyers, *et al, op cit,* Ref 2. For an overview, see S. Meyers and L. Schipper, 'World Energy Use in the 1970s and 1980s: Exploring the Changes', *Annual Review of Energy and the Environment,* Vol. 17, 1992.

[4] For an overview of the 'efficiency potential' literature, see Chapter 9 in Schipper and Meyers, *et al, op cit,* Ref 2. See also International Energy Agency, *Energy Efficiency and the Environment,* Paris, France, 1991.

[5] Population is obviously a different kind of activity measure than are measures of economic output or physical activity. There are many different energy-using activities that take place in homes but no single measure of 'output'.

*Structural change* is defined somewhat differently among the sectors. In manufacturing it refers to shifts in the shares of total sectoral activity accounted for by each of the six subsectors that we use (iron & steel, non-ferrous metals, paper & pulp, chemicals, building materials, and all other industries). In transportation, it refers to shifts in the shares of total sectoral activity accounted for by each of the transport modes (automobiles, rail, bus, and air for passenger travel; truck, rail, and ship for freight transport). In the residential and service sectors, what we refer to as structural change is rather different. In the residential sector, we define it with respect to household size, per capita ownership of energy-using equipment, and, for space heating, dwelling area per person. In the service sector, it means growth in penetration of electrical equipment relative to value added. In both cases, it includes shifts between electricity and fuels for heating.

Structural change is shaped by factors specific to each sector. Changes in domestic demand and the competitiveness of domestic industries (internally and externally) obviously play a leading role in the manufacturing sector, but national industrial policy may be a factor as well. For passenger travel, household income and the cost and convenience of different modes are important. In freight transport, the modal structure is strongly influenced by the type of goods that are moved, the time requirements of users, and the state of the transport infrastructure. Income and demographic factors are the major determinants of structural change in households, but saturation of major energy services appears once a certain income level has been reached. In the service sector, structural change as we define it is driven mainly by the desire to provide a comfortable and productive work environment for employees and an attractive environment for guests (such as in shops and hotels).

*Energy intensity* expresses the amount of energy used per unit of activity for each major end use or subsector. (The aggregate energy intensity of each sector is determined by its subsectoral energy intensities and structure.) The thermodynamic efficiency that is 'built into' equipment and systems is a major determinant of energy intensities. It depends on the characteristics of various components, and how they interact. (For example, the energy efficiency of a motor system is a function of the wiring, power conditioning equipment, controls, and transmission components, as well as the efficiency of the motor itself.) How systems are operated and maintained and how well their capacity is utilized shape energy intensity in actual use. Change in the scale of factories or equipment also impacts energy intensities. Behavior plays a role in many end uses.

Other factors affect intensities (as we define them) in each sector. In manufacturing, changes in the product mix affect the energy intensity of particular industries. (For example, the energy intensity of the paper & pulp industry is affected by shifts in production between energy-intensive pulp and finished paper goods.) For various end uses, changes in the average characteristics of equipment (independent of the thermodynamic energy efficiency) shape the average energy intensity (for example, shift to larger cars or appliances).

Together, change in activity, structure, and energy intensities shape trends in energy use in each sector. One can measure the impact of any one of the three factors by holding the other two constant at base-year values. We employ a method that is rooted in the use of fixed-weight or Laspeyres indices.[6] The annual growth rates in energy use caused by activity, structural, and intensity changes reported later add, but because of important cross terms, the absolute percentage changes in energy use do not.

In our historical analysis, we keep track of use of different fuels (including biomass). In the scenarios, we combine oil, natural gas, coal, and heat into 'fuels', and consider the prospects separately

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[6] For a description, see R. Howarth, *et al*, 'Manufacturing energy use in eight OECD countries: Decomposing the impacts of changes in output, industry structure, and energy intensity', *Energy Economics*, Vol. 13:135-42, 1991.

for fuels and electricity (including shifts among them for certain sectors).[7] We then convert final electricity use to primary energy use using OECD-average values for generation and line losses.

## 4. Description of the Scenarios

The focus of the scenarios is on the prospects and possibilities for change in energy intensities. Each scenario embodies the same growth in activity and structural change, with slight differences, as described in the section following this one.

Despite the plateau in the recent past alluded to earlier, over the next 20 years most energy intensities in the OECD countries will decline as new capital stock replaces the old and as improvements are made to buildings and industrial facilities. The extent of decline will depend on many factors, including economic growth, energy prices, technological developments, and government policies. Judging the respective roles that these forces have played in the past is itself a challenging task, for although dozens of studies have been performed, they have not yielded conclusive results. Assessing how these factors will evolve, and how energy intensities will change in response, is obviously very difficult.

The scenarios are the result of an intellectual exercise, not a prediction. We do not contend that the various energy intensity values will necessarily result if prices and policies change as described. Nor do we contend that these price and policy changes would be easy to implement. However, we believe the scenarios depict what could occur based on both past experience and realistic technological capacities. Whether industrial societies are institutionally capable of the major changes that would be required in the most extreme scenario is an important question beyond the scope of this analysis.

**Trends.** This scenario reflects a world in which energy prices rise slowly and only modest attention is given to energy efficiency. In keeping with the current expert concensus, the world oil price increases by around 50% between 1990 and 2010, with more of that increase coming in the first decade of the next century than in the 1990s. By comparison, the increase in real oil prices in 1972-1985 was around threefold. Natural gas prices increase somewhat more than oil due to the premium placed on this fuel, while coal prices rise somewhat less; electricity prices rise only slightly, since the fuel component is only part of the total price.[8] The role of policies is limited to present appliance standards in the US, existing building codes, and a slow increase in the participation of US and European utilities in demand-side management (DSM) programs. In productive economic sectors, reductions in energy intensity are more the result of efforts to improve productivity generally than to reduce energy costs specifically.

**Efficiency Push.** This scenario envisions a future in which full adoption of marginal-cost energy pricing and internalization of many environmental and other externalities boosts real energy prices to users by 25-50% relative to 'Trends'. (These increases should occur by the late 1990s if their full effect is to be felt by 2010.) In addition, governments step up the role of energy-efficiency policies, especially those for which there is already moderate political support. Utilities are encouraged through incentives or other means to implement DSM programs more aggressively (similar to what many utilities in the US are now doing). No major technological breakthroughs are assumed, but there is some increase in R&D related to energy efficiency. There is also increased improvement in the efficiency of electricity supply, including more use of cogeneration.

**Vigorous Effort.** This scenario depicts what seems to us the most that could plausibly be achieved within a 20-year time horizon. The limit is not so much technology itself, but rather the rate at which

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[7] We have excluded use of fuels for non-energy purposes such as petrochemical feedstocks.

[8] These assumptions roughly correspond to our interpretation of the current consensus. See, for example, US Department of Energy, *Annual Energy Outlook 1992*, Washington, DC, USA, 1992.

more efficient technologies and practices could penetrate widely into the capital stock. Energy prices rise to 50-100% higher than in 'Trends', reflecting incorporation of strong carbon taxes as well as more aggressive internalization of externalities associated with local environmental problems related to energy production and use. National and international consensus to greatly improve the energy efficiency of new equipment and systems is reached in the mid-1990s, leading to rapid response from equipment manufacturers, national and local energy supply authorities, and other actors. Strong policies are implemented to accelerate the market's adoption of high-efficiency energy-using technologies, and utilities pursue DSM options with vigor. Manufacturers of energy-using equipment receive a clear signal that the market will place a high value on energy efficiency, and thus devote more effort to incorporating *and* marketing energy-saving innovations. Motor vehicles are given special attention, and comprehensive programs of retrofitting buildings and factories are undertaken as well. Various innovative policies now in pilot or discussion stages are widely implemented to encourage production and purchase of very efficient technologies. Energy-efficiency R&D is pursued in earnest, leading to cost reductions in such technologies. Education and training for those who design and maintain energy-using systems is emphasized. In addition to much more efficient vehicle technology, there is a modest shift toward smaller cars. The increase in electricity supply efficiency also accelerates.

## 5. Activity and Structural Change

The impacts of change in activity and structure in each sector for 1985-2010, and the overall impacts on total energy use, are shown in Table 1.[9] These values are the same in each scenario (except as noted below). Population grows at 0.6%/year. Growth in GDP is assumed to average 2.8%/year.[10] In keeping with the projections of economic forecasters, industry (mostly composed of manufacturing) grows more slowly than GDP (2.4%), while services grows faster (3.1%). Activity growth in travel is based on the change estimated for each major mode. The number of automobiles per 1000 people grows from 400 to 480, and average distance travelled per vehicle rises by 10%. Distance travelled per vehicle increases somewhat less in the 'Vigorous Effort' scenario in response to higher fuel prices and policies to encourage mass transit; this has a slight effect on the structure of travel. The load factor for cars remains at 1.5 passengers. Domestic air travel increases at 5.0% per year (compared to 6.5% in 1972-1985). While air travel in Europe will grow rapidly, the US will see less increase than in the past due to some saturation in demand. In total, domestic travel grows faster than GDP (3.1%). Freight transport t-km grows at the same rate as industrial GDP.

Weighting the activity growth rates by the share of 1985 energy use accounted for by each subsector or end use, the combined effect of activity growth is to increase final energy demand at a rate of 2.4% per year and primary demand at 2.3%. The main reason why growth in the energy-weighted 'activity factor' is lower than GDP is that manufacturing, which is relatively energy-intensive per unit of value added, grows more slowly than GDP, while services grows faster. The effect of activity growth is smaller on demand for electricity (2.1%) than for fuels, since the sectors where electricity is relatively important (households and services) are together growing more slowly than transport, for which electricity use is minor.

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[9] For a more in-depth discussion of future prospects for activity and structural change in the OECD countries, see Chapter 8 in Schipper and Meyers, *et al*, *op cit*, Ref 2.

[10] In its *International Energy Outlook 1992*, the US Department of Energy assumes average annual growth in OECD GDP of 2.7% in 1990-2000 and 2.6% in 2000-2010. Actual growth in 1985-1990 was 3.4%. These assumptions are based on modelling by Wharton Econometric Forecasting Associates.

**Table 1. Change in OECD Energy Use Due to Activity and Structural Parameters, 1985-2010 (avg. annual rates of change)**

| Sector | Activity | | Structure |
|---|---|---|---|
| | Measure | Impact | |
| Industry | VA | 2.4 | -0.4 |
| Fuels | - | - | -0.5 |
| Electricity | - | - | -0.1 |
| Travel | p-km | 3.1 | 0.2 |
| Freight transport | t-km | 2.4 | 0.3 |
| Residential | pop | 0.6 | 1.2 |
| Fuels | | | 0.9 |
| Electricity | - | - | 1.8 |
| - appliances | - | - | 1.6 |
| - heat, hw, cooking | - | - | 2.1 |
| - lights | - | - | 1.2 |
| Services | VA | 3.1 | -0.1 |
| Fuels (heat,hw) | - | - | -0.4 |
| Electricity | - | - | 0.4 |
| - Heat, hw | - | - | 0.9 |
| - Lights | - | - | 0.0 |
| - Cooling, vent. | - | - | 0.9 |
| - Other | - | - | 0.4 |
| Total[a] | | | |
| Fuels | - | 2.4 | 0 |
| Electricity | - | 2.1 | 0.8 |
| Final energy | - | 2.4 | 0.1 |
| Primary energy | - | 2.3 | 0.3 |

[a] Activity and structure impacts are weighted by the end-use shares of 1985 energy use.

The projected effect of structural change varies among the sectors (and for fuels and electricity). The rates cited describe the impact on energy use of structural change alone; i.e., how energy use would evolve if activity and energy intensities remained constant.

In manufacturing, structural change toward less energy-intensive industries decreases final energy use by 0.4% per year, less than the actual reduction of -0.8% per year in the 1972-1985 period. This assumption is subject to some debate; it is our view that some of the structural change in the past was due to specific shifts (such as the sharp decline in the US steel industry's value added) that may have less effect in the future. To be sure, the next 20 years may see more shifts in the product mix (toward higher value-added goods) *within* industry groups, but in our analytic framework, this effect is part of energy-intensity change. The impact of structural change is much greater on fuel use than on electricity demand, since the industries whose importance is declining are more fuel-intensive than the others.

In passenger travel, structural change increases energy use by 0.2% per year. The effect is mainly the result of air travel growing faster than other modes, but growth in the share of automobiles in Europe and Japan also plays a role. For freight transport, the share of trucks, which are much more energy-intensive than rail, increases as bulk commodities become less important in the OECD economies and production facilities become more dispersed. This trend pushes energy demand for freight transport up by 0.3% per year.

Structural change has the largest impact in the residential sector. Heated area per capita grows by 35% (with more growth in Europe and Japan than in the US). The area heated by fuels grows 90% as much, as electricity assumes a rising share of the market. The per capita demand for cooking and water heating services increases somewhat due to the effect of declining household size; a shift from fuels to electricity also occurs. Lighting grows with house floor area. Rise in appliance ownership increases per capita electricity use for appliances by 50%, but this is much less than the nearly 100% effect during the 1972-1985 period. In total, structural change increases residential final energy use by 1.2% per year, which is less than in the past. In this case, the impact is greater on electricity (1.8%) than on fuels (0.9%), since the driving factors are growth in ownership of electric appliances and a shift toward electricity in space and water heating.

In the service sector, decline in the share of floor area heated with fuels has a downward effect on fuel use, but growth in electric heating and penetration of other electrical equipment pushes upward on electricity use. For non-heating electrical end uses, penetration of cooling and ventilation is 1.25 times more rapid than services VA, lighting grows the same as VA, and other building services grow 10% faster.

Because impacts in some sectors balance those in others, the total effect of structural change (weighted by 1985 energy use patterns) is slight. It increases final energy demand by only 0.1% per year, and primary energy use by 0.3% per year. The *combined* effect of structural change and activity growth in each sector is shown in Figure 1. In total, if energy intensities remained unchanged, OECD primary energy use would double between 1985 and 2010.

## 6. Change in Energy Intensities

The average annual rates of change in key energy intensities in each scenario are shown in Table 2. For comparison, historical rates achieved between 1972 and 1985 are also shown. For most end uses, the rates shown were calculated based on the intensities estimated for 2010. For industry, the estimated rates of change were the basis of intensity decline, and the intensity values for 2010 were calculated based on those rates. Given the difficulty of estimating how much the actual energy intensity (in terms of value added) might or could change within each industrial subsector, we believe this is a more tractable approach.[11] The scenarios also include relatively minor end uses not listed in Table 2 (such as rail and buses in transportation).

The intensity values chosen for each scenario were based in part on several rather simple judgements. In 'Trends', the stock-average intensities in 2010 are near the average values for new technologies in 1990 in many cases. In 'Efficiency Push', most intensities decrease between 1985 and 2010 at approximately the same rate as they did between 1972 and 1985. For many end uses, the average intensity levels in 2010 are near the lowest of new systems in 1990. In 'Vigorous Effort', the rate of decline in intensities resembles that which occurred in the 1979-1983 period, when energy prices and programs stimulated much action to save energy. In many cases, average intensities in 2010 lie below the lowest of new systems on the market in 1990, but are close to the levels achieved by the best products expected to be

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[11] The difficulty lies not only in assessing technological trends and potentials in each industry, but also in evaluating the impact of change in the product mix within industries, which also affects energy intensity.

available by the mid-1990s, or at levels represented by prototypes.

**Industry.** Energy intensities in manufacturing have declined for many decades due to adoption of new production technologies. The rate of decline in 'structure-adjusted' fuel intensity in 'Trends' (2.5%/year) is slower than what occured in the 1972-85 period (3.7%/year).[12] There is continuation of the trend of technological innovation, but the slower growth in fuel prices results in less emphasis on energy saving. Fuel intensity falls by 3.0%/year in 'Efficiency Push' as manufacturers respond to higher energy prices. The pace is more rapid (4.0%/year) in 'Vigorous Effort', as the substantial rise in energy prices causes companies to adopt advanced technologies that would otherwise not be economic. In addition, expanded use of cogeneration allows considerable substitution of heat for direct fuel combustion.

Electricity intensity declines by 0.3%/year in 'Trends'. There is increasing use of electricity in many applications, but higher efficiency still results in a net decline in intensity. The drop of 0.5%/year in 'Efficiency Push', is comparable to the historic trend from 1972-1985, reflects higher prices and policies to encourage use of high-efficiency motors. In 'Vigorous Effort', the rate of decline is twice that of 1972-85, reflecting the impact of higher prices, utility DSM programs, and strong standards for electric motors.

The difference between the 'Efficiency Push' scenario and 'Trends' is relatively small. The reason is that the primary force of intensity reduction in industry is ongoing technological change that is relatively independent of energy prices. There is also more limited scope for efficiency policies and programs in manufacturing, relative to other sectors.

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[12] The historical analysis considered energy intensities in six industrial subsectors. 'Structure-adjusted' means that the shares in total industrial value added of each of these subsectors has been held constant at base year levels. See R. Howarth, *et al, op cit,* Ref 6.

**Table 2. Average Rate of Decline in OECD Energy Intensities (%/year)**

| Sector | 1972-1985 Actual | 1985-2010 Scenarios Trends | Efficiency Push | Vigorous Effort |
|---|---|---|---|---|
| Industry (energy/VA)[a] | | | | |
| Fuels | 3.7 | 2.5 | 3.0 | 4.0 |
| Electricity | 0.5 | 0.3 | 0.5 | 1.0 |
| Travel (energy/p-km) | | | | |
| Cars[b] | 2.2 | 1.0 | 2.0 | 4.1 |
| Air | 3.9 | 1.2 | 2.0 | 2.8 |
| Freight transport (energy/t-km) | | | | |
| Trucks | (-)0.4 | 0.4 | 1.1 | 2.7 |
| Residential (energy/capita) | | | | |
| Fuels: heat, hw, cooking | 1.8 | 0.6 | 2.0 | 5.4 |
| Electricity | | | | |
| - appliances | 1.2 | 0.9 | 1.7 | 2.8 |
| - heat, hw, cooking | 1.7 | 1.2 | 2.8 | 4.2 |
| - lights | 0.8 | 1.2 | 3.7 | 5.5 |
| Services (energy/VA)[c] | | | | |
| Fuels | 2.7 | 0.6 | 2.0 | 3.1 |
| Electricity | 1.2 | 0.7 | 1.7 | 2.7 |
| Total[d] | | | | |
| Fuels | 2.5 | 1.2 | 2.1 | 3.8 |
| Electricity | 0.8 | 0.5 | 1.4 | 2.4 |
| Final energy | 2.3 | 1.1 | 2.0 | 3.6 |
| Primary/final elec ratio | 3.24 | 2.92 | 2.85 | 2.77 |
| Primary energy | 2.1 | 1.0 | 2.0 | 3.6 |

[a] The rates refer to the change in 'structure-adjusted' energy intensity (see text).
[b] Energy/km.
[c] The estimated impact of changes in space heating energy choices and in the penetration of electrical equipment has been removed from aggregate fuels and electricity intensity. The values given represent the weighted intensity of several end uses.
[d] Intensities are weighted by end-use shares of 1985 final energy use.

**Transportation.** We focus on three subsectors—automobiles, air travel and truck freight—which together account for over 75% of OECD transportation energy use. While reductions in intensities of other travel and freight modes are likely to occur, they are not very significant in the overall picture.

In 'Trends', automobile fuel intensity declines from 10 liters/100 km (24 mpg) in 1985 to about 8.5 l/100 km (28 mpg) in 2010. Most of the change occurs in the US.[13] The slow improvement reflects the

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[13] Changes in the US figure significantly in the OECD average, since the US accounts for about 57% of OECD automobile fuel use. In considering the scenario intensity levels, one must bear in mind that actual on-the-road intensity is some 20% higher than test intensity.

plateau in new car fuel economy in recent years, as well as the effect of increasing traffic congestion. In 'Efficiency Push', intensity declines to 6.9 l/100 km (35 mpg). Higher fuel prices increase consumer demand for fuel efficiency as a vehicle attribute, and modest regulations or agreements cause automobile producers to focus more effort on efficiency. In 'Vigorous Effort', automobiles use only 4-5 l/100km (48-60 mpg) in 2010, roughly the level of the most efficient small cars sold in 1990. Higher gasoline prices and new car registration fees that vary with fuel efficiency (and emissions) create strong market demand, which helps convince car manufacturers to commercialize various fuel-saving features (some of which are now found only on lightweight prototypes). In addition, there is some shift toward smaller cars. Reaching this level of fuel economy would require agreement among political leaders, citizen groups, and automobile manufacturers so that efficiency goals have wide support.

The relationship between historic changes in stock-average energy intensities, the intensity of typical new equipment in the late 1980s, and projected future energy intensities is illustrated in Figure 2 for the case of automobiles. The figure also shows how different the situation is between the US, where the average new car is much less energy-intensive than the stock average, and Europe and Japan, where the two are roughly equal. By 2010, of course, very few cars built before the late 1980s will still be on the road. For all three groups, achieving a significant reduction in average intensity will require a reversal of recent trends.[14]

The intensity of air travel declines at 1.2%/year in 'Trends', much less than the 3.9% rate of decline during the 1972-1985 period. This reflects the slowing of intensity reduction in recent years, a slower rate of improvement in load factors, and somewhat less turnover and retrofit of aircraft. In 'Efficiency Push', intensity declines more rapidly as airlines respond to higher prices; the rate is only half of its historical rate, but intensity in 2010 is nonetheless 40% lower than in 1985. This scenario reflects replacement of almost all existing aircraft by models with the lowest intensities available in 1990. In 'Vigorous Effort', the intensity declines at close to 3%/year as a result of significant penetration of propfan aircraft.

The intensity of truck freight declines at 0.4%/year in 'Trends'. The historic upward trend in intensity in the US (which was due largely to operational factors) reverses as various technologies penetrate the fleet and operations improve. In 'Efficiency Push', intensity declines at 1.1%/year as higher fuel prices provoke careful effort to improve both trucks and freight operations. In 'Vigorous Effort', there is much faster decline (2.7%/year), reflecting widespread use of advanced technologies made available through accelerated R&D.

**Residential Sector.** The 'Trends' scenario envisions a continued but slow pace of retrofitting of existing homes. Entrance of new homes into the stock also contributes to decline in average heating intensity, although the 2010 stock-average value remains above the 1987 average for *new* homes. (In Japan, indoor comfort levels are increasing; consequently, space heating intensity is higher in 2010 than in 1987 in 'Trends'.) Overall, intensity of fuel use for space heating, water heating, and cooking declines by 0.6%/year (compared to 1.8%/year in 1972-85). In 'Efficiency Push', stepped-up retrofit activity and programs that target new homes cause fuel intensity to fall by 2.0%/year, about the same rate as between 1972 and 1985. In 'Vigorous Effort', much higher prices and strong programs cause a large reduction in heating intensity relative to 'Efficiency Push' in Europe and the US. The average heating intensity in 2010 is well below the level of new homes in 1987 in the US and Europe. Space heating intensity in new homes falls close to the levels now found in Scandinavia. Incentives for retrofit are substantial, and efforts are made to coordinate thermal improvements with other modifications to homes. More careful

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[14] For a discussion of past trends in automobile energy intensities, see L. Schipper, R. Steiner, and S. Meyers, *Trends in Transportation Energy Use, 1970-1988: An International Perspective,* Lawrence Berkeley Laboratory, Berkeley, CA, USA, 1992.

energy management in the home, induced by higher fuel prices, is facilitated by advanced control systems.

For electric appliances, the average intensity in 2010 in 'Trends' is comparable to that of new appliances in the late 1980s. The decline is driven mainly by the current US efficiency standards and modest efforts to market energy efficiency elsewhere. In 'Efficiency Push', stronger policies and programs, especially in Europe, cause the average intensity to fall to near the level of the present market lowest (which is about half the level of the average new appliance in 1987). 'Vigorous Effort' includes programs to push the efficiency frontier in new appliances and to encourage market uptake of these devices. The average intensity of appliances in 2010 is well below the lowest intensity of products available in 1990. 'Vigorous Effort' also embodies considerable reduction in energy intensity of lighting as compact fluorescent lamps come into widespread use. Utility DSM programs play a major role in accelerating the efficiency of electric end uses.

**Service Sector.** In the 'Trends' scenario, the structure-adjusted fuel intensity declines by only 0.6%/year.[15] The decline is much slower than in the 1972-1985 period (2.7%), which reflects some saturation of the retrofit potential and the slow penetration of new buildings. The structure-adjusted electricity intensity (which incorporates the intensity of several end uses) decreases by 0.7%/year, also less than in the past. In 'Efficiency Push', higher prices cause fuel intensity to decline at 2.0%/year. Electricity intensity falls at a rate of 1.7%/year, in part due to the increasing attention given to the service sector by utility DSM programs. In 'Vigorous Effort', fuel intensity declines at 3.1%/year as retrofit activity becomes more ambitious. Electricity intensity falls considerably as strong DSM programs and other efforts push the market penetration of cutting-edge technologies. A large share of new buildings soon incorporate energy-saving designs and technologies that are found in the most efficient new buildings today.

**Summary.** The energy intensities of key end uses in each scenario (relative to 1985 levels) are shown in Figure 3. Whereas in 'Trends' the intensity reductions relative to 1985 are mostly in the 15-25% range, 'Efficiency Push' results in reductions of 35-50%. Intensities in the 'Vigorous Effort' scenario are 50-75% less than 1985 levels. The intensities of automobile travel and home heating in particular fall considerably in the latter case.

## 7. Total Energy Use

OECD energy use in 1985 and in each 2010 scenario are shown in Table 3. Use of electricity grows much faster in 'Trends' than does use of fuels, which contributes to growth in primary energy use. The reduction in 'Efficiency Push' relative to 'Trends' is the same (20%) in each case, but in 'Vigorous Effort' use of fuels falls more than electricity demand (due largely to the emphasis placed on automobiles in this scenario).

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[15] The fuel and electricity intensities incorporate adjustments to remove the effects of structural change described earlier. These effects have been roughly estimated for the historical period in order to estimate the scenario values. The actual unadjusted values in 1972-1985 were -3.6%/year for fuel intensity and +1.3%/year for electricity intensity.

**Table 3. OECD energy use: 1985 and 2010 scenarios (exajoules)**

| | 1985 Actual[a] | 1985-2010 Scenarios | | |
|---|---|---|---|---|
| | | Trends | Efficiency Push | Vigorous Effort |
| Fuels | 91 | 115 | 92 | 61 |
| Electricity | 17 | 29 | 23 | 19 |
| Final energy | 108 | 144 | 115 | 79 |
| Losses | 36 | 56 | 43 | 33 |
| Primary energy | 144 | 200 | 158 | 112 |

[a] The values do not include non-energy uses of fuels.

Figure 4 depicts total OECD primary energy use attributable to each sector in 1985 and in each scenario. In 'Trends', the intensity reductions are not large enough to balance the growth due to the activity and structural changes described above. OECD primary energy use rises at an average rate of 1.3% per year, and is about 40% higher in 2010 than in 1985. The improvements in 'Efficiency Push' yield a reduction of 22% relative to 'Trends', and demand is about the same as it was in 1989 (which was 7% higher than in 1985). In the 'Vigorous Effort' scenario, energy use is 44% less than in 'Trends', and is nearly 30% less than the actual use in 1989. The energy/GDP ratio is about 60% lower than in 1985.

In reality, the reduction in energy demand in the 'Efficiency' and 'Vigorous Effort' scenarios would likely be somewhat less than described above. The reason is that lower demand caused by energy conservation would tend to depress energy prices. Unless prices are kept up by government taxation (over and above what we have assumed in the scenarios), the reduction would tend to lower the rate of price-induced efficiency increase and also discourage energy-saving behavior. The size of this feedback effect would vary among sectors, but is probably small in the aggregate.

As mentioned earlier, we have not attempted to project changes in final use of specific fuels in the scenarios. Nor have we attempted estimates of fuel shares for electricity generation. The conventional wisdom, however, holds that even without carbon taxes, the share of natural gas in *fuel* consumption is very likely to increase in all end-use sectors and in electricity generation as well — primarily for reasons related to local environmental problems. Thus, the reductions in $CO_2$ emissions in each scenario (relative to 1985) would be somewhat larger than the reductions in *energy* consumption. In addition, the energy pricing policies in the 'Efficiency Push' and 'Vigorous Effort' scenarios would encourage use of renewable energy technologies for both final uses and for power generation, especially if accompanied by accelerated R&D for these technologies. Thus, the overall reduction in $CO_2$ emissions would in these scenarios could be significantly larger than the reductions in energy use cited above.

## 8. Discussion

Each scenario assumes the same growth in GDP and activity at the sectoral level. In actuality, economic growth and the associated investment and stock turnover will affect the degree of efficiency improvement that occurs in the future. Faster economic growth leads to more investment and stock

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[15] Projections from the US Department of Energy based on aggregate energy-economy models show average growth in OECD primary energy consumption of about 1.2% per year between 1989 and 2010. See *Annual Energy Outlook with Projections to 2010*, Washington, DC, USA, 1991.

turnover, so efficiencies tend to improve faster. The efficiency improvements described in the scenarios are plausible with the assumed rates of economic growth, but more improvement might occur 'naturally' with higher growth. On the other hand, faster economic growth will provide consumers with more income that could contribute to larger homes and greater travel.

Unlike formal energy-economy models, the scenarios do not have an explicit feedback between the substantial energy-price increases envisioned and GDP growth. If the increases would lead to lower GDP growth than we assumed, this would mean slower stock turnover and thus could make it more difficult to achieve the scenario intensities by 2010. The 'top-down' models that economists have used to estimate the costs of reducing greenhouse-gas emissions indicate total GNP losses of some 1% to 3% for emissions cutbacks on the order of 50%.[16] The time-frame for such a reduction is longer than envisioned in our scenarios (which are not explicitly focused on greenhouse-gas emissions), but the pace is roughly comparable with the 'Vigorous Effort' scenario. Thus, the impact on GDP growth would appear to be quite small. It would depend on how the energy taxes envisioned in the scenarios were recycled back into the OECD economies. Other (distortionary) taxes could be reduced proportionally, which could have a large economic efficiency value,[17] or investment tax credits could be expanded (which would help businesses make capital investments that would enhance energy efficiency).

An assessment of the full range of impacts that might occur in the 'Efficiency Push' or 'Vigorous Effort' scenarios is beyond the scope of this exercise. In addition, we have not performed an economic evaluation of the efficiency improvements embodied in the scenarios. We would contend that describing a particular level of energy intensities as 'least-cost' from a societal perspective is fraught with difficulty. Based on the 'efficiency potential' literature, however, we believe that the efficiency levels in the 'Efficiency Push' scenario would be roughly cost-effective from a social perspective based on projected market prices (i.e., before the imposition of energy taxes). The efficiency levels in the 'Vigorous Effort' scenario may be cost-effective in some cases, and many, if not most of them would probably be so if energy prices incorporated the environmental externalities associated with energy supply and use, or if R&D lowered costs of implementation.

Even if certain levels of energy intensities are cost-effective, that is far from a guarantee that they will come about. One way of judging how realistic the intensity declines described in the 'Efficiency Push' and 'Vigorous Effort' scenarios are is to compare the rates of change to historical experience. The average decline in the weighted average of the energy intensities is 2.0%/year in "Efficiency Push", slightly less than the 2.3%/year achieved between 1972 and 1985. (To express the combined effect of the various intensity changes, we weighted each intensity according to 1985 energy use patterns.) In 'Vigorous Effort', average energy intensity declines by 3.6%/year, close to the rate experienced in many countries during the period 1979-1982, when energy prices rose sharply and various policies were implemented. Sustaining such a rate over 20 years would require a major and concentrated effort. It would not take an enormous amount of technological innovation, but would require great effort to accelerate the market penetration of highly energy-efficient technologies and practices.

While the 'Vigorous Effort' effort scenario is undoubtedly a very ambitious case, it does not exhaust the actions that society might undertake to restrain energy use and reduce local environmental problems. For example, we have not assumed major changes in land-use planning that could have significant long-run impacts on transportation energy use. Nor have we assumed substantial changes in

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[16] W. R. Cline, *Global Warming: The Economic Stakes,* Institute for International Economics, Washington, DC, 1992.

[17] R. Shackleton, *et al,* The Efficiency Value of Carbon Tax Revenues, US Environmental Protection Agency, Washington, DC, USA, 1992.

lifestyles or basic patterns of material consumption. Yet such changes might well be associated with a world in which environmental awareness and concern are raised to new levels. To the extent that they do in fact occur, the pressure to accelerate adoption of new technologies would be lessened. In the long run, of course, change in technology, social conditions, and values will shape lifestyle, behavior, and consumption patterns in ways that can only be guessed at from our present vantage point. If a concensus develops that serious restraint on $CO_2$ emissions is called for, understanding how to influence these factors is likely to be an important complement to policies designed to accelerate adoption of better technologies.

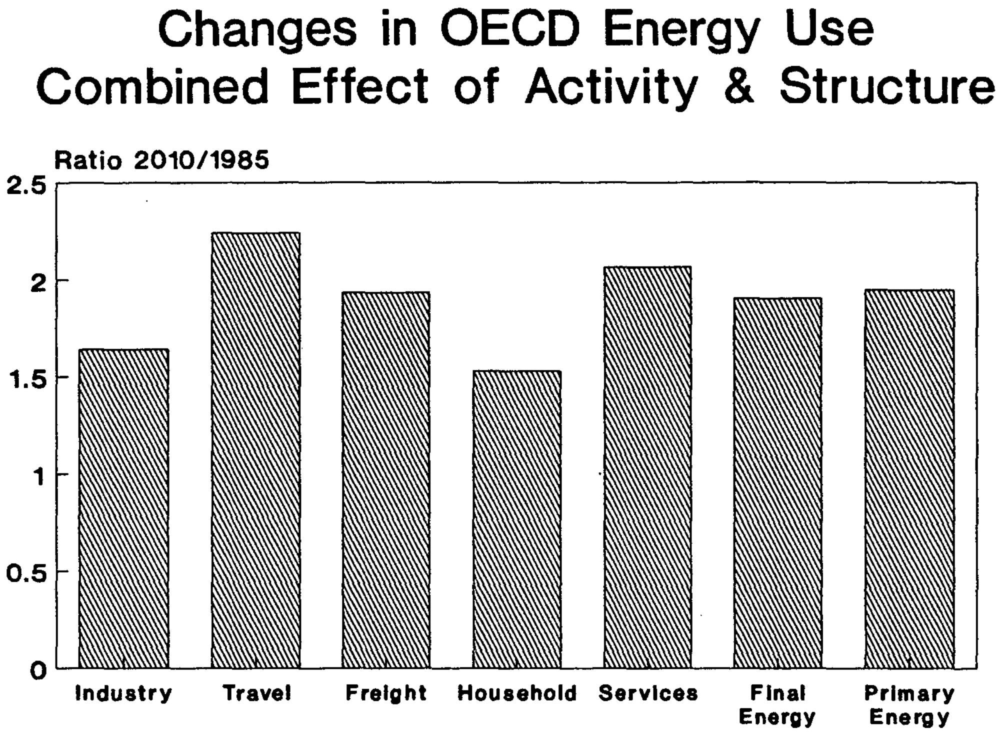
## 9. Conclusion

We do not claim that the scenarios presented here are a definitive analysis of what is likely to occur in the OECD countries over the next 20 years if energy prices and efficiency policies change as described. Rather, they represent a reasonable judgement grounded in considerable analysis of past trends and consideration of future prospects for energy use in each sector. The scenarios delineate an important (if somewhat vague) boundary between a relatively easily attainable improvement in efficiency and a more problematic level of change. The scenarios suggest that OECD energy use in 2010 could be 20-25% less than where trends are pointing (or about equal to demand in 1989) if fairly strong efforts are made. To increase that reduction to 40-45% would be very challenging, but does not seem impossible.

Whether the boundary conditions of the scenarios (especially 'Vigorous Effort') are likely to come about is an open question. In some respects, certain aspects of the 'Efficiency Push' scenario are in fact materializing. Utility DSM programs are growing rapidly in the US and seem likely to play a stronger role in Europe and perhaps Japan as well. Efficiency standards for various building-related technologies are included in new legislation due to be enacted in the US, and standards for appliances sold in the European Community (EC) may be on the horizon. Internalization of environmental externalities in energy prices has passed beyond the discussion stage in some countries, and imposition of a carbon tax in the EC seems possible. In other important areas, however, especially automobiles, there is much less action with respect to energy efficiency.

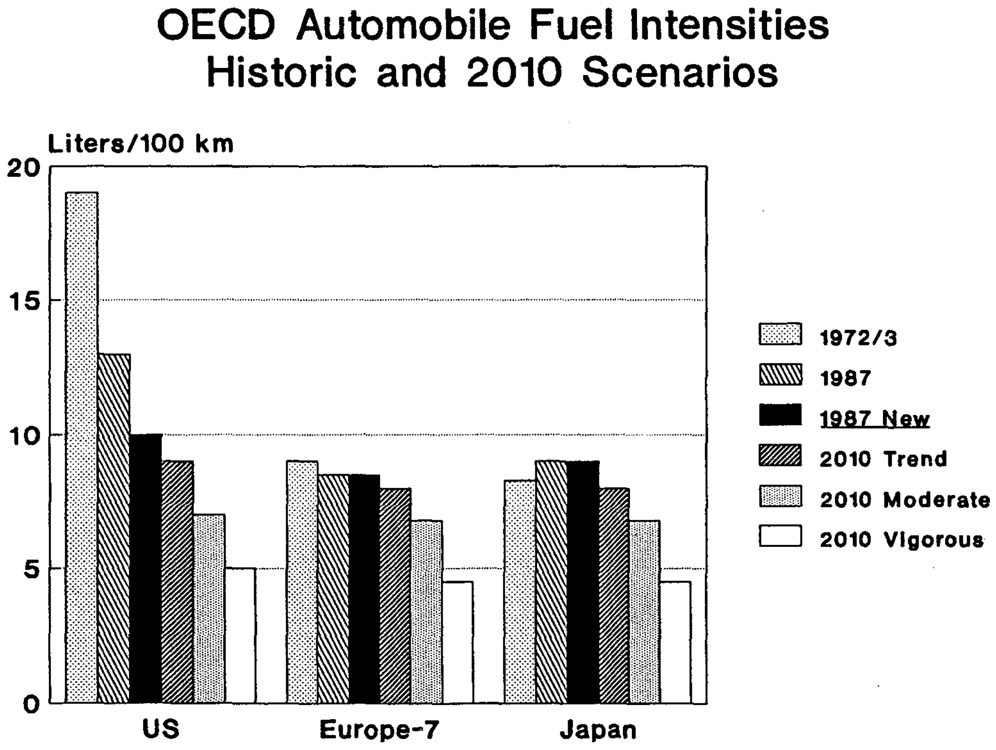
Given the political realities in the OECD countries, the energy-efficiency policies envisioned in the scenarios have greater prospects than the energy taxes. Yet experience suggests that trying to stimulate the market's interest in energy efficiency without making energy more dear at the same time is likely to lead to less than satisfactory results.

**Note:** This article is an expanded version of material published in *World Energy: Building a Sustainable Future,* by the authors, published by the Stockholm Environment Institute, 1992. Richard Howarth and Ruth Steiner made substantial contributions to the historical analysis on which the scenarios are built. Charles Campbell produced the graphics.



Changes in OECD Energy Use
Combined Effect of Activity & Structure

Figure 1



OECD Automobile Fuel Intensities
Historic and 2010 Scenarios

Figure 2

## OECD Energy Intensities
## 2010 Scenarios

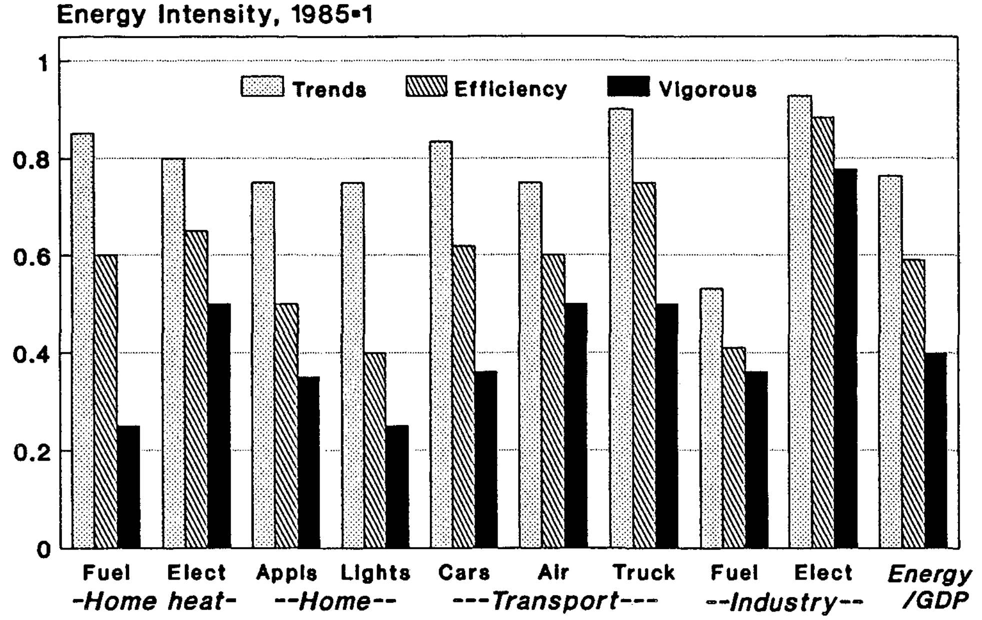


Figure 3

## OECD Primary Energy Use
## 1985 Actual and 2010 Scenarios

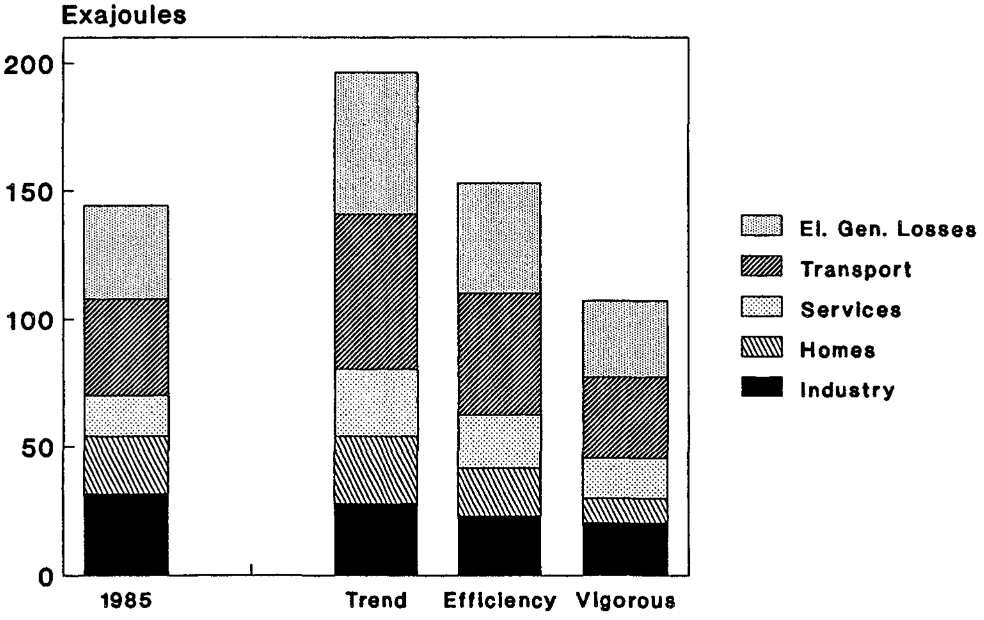


Figure 4

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