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Modelling Regional Energy Use for Evaluating Global Climate Scenarios

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ABSTRACT

The Energy-Economy model presented in this report is a submodel of the integrated IMAGE 2.1 model (Integrated Model for Analyzing Greenhouse Effects). The Energy-Economy submodel computes total energy use, with a focus on final energy consumption in end-use sectors, based on economic activity levels and energy conservation potential ("end-use approach"). The IMAGE 2.1 model then computes related emissions of greenhouse gases per region. The Energy-Economy model enables policy planners to generate and develop consistent regional and global scenarios for energy use and industrial processes. For the purpose of generating scenarios of energy conservation and emission control strategies, various techno-economic coefficients in the model can be modified. In this paper calibration of parameters of the model is presented using data of the 1970-1990 period of the residential and industrial sector in Western and Eastern Europe and CIS. In addition, applications of the model are presented for some specific scenario calculations. Future extensions of the model are in preparation.

SAMENVATTING

Dit rapport presenteert het energie economie model zoals geïmplementeerd in het geïntegreerde IMAGE 2.1 model (Integrated Model for Analyzing Greenhouse Effects). Het Energie Economie submodel berekent energiegebruik in eindverbruikssectoren gebaseerd op economische aktiviteitenniveaus en het energiebesparingspotentieel ("end-use approach"). Vervolgens berekent het IMAGE 2.1 model emissies van broeikasgassen per regio. Het Energie Economie model stelt modelgebruikers en beleidsmakers in staat om consistente toekomstbeelden te ontwikkelen voor economische ontwikkeling, omvang van industriële processen en de energievraag. Verscheidene technisch economische parameters van het model kunnen worden gewijzigd om een beeld te krijgen van de effecten van energiebesparing en van andere strategiën gericht op het reduceren van emisssies van broeikasgassen. In dit rapport wordt uiteengezet hoe de calibratie van het model heeft plaatsgevonden. Dit wordt geïllustreerd aan de hand van een aantal voorbeelden; de sectoren huishoudens en industrie in de regio's West- en Oost-Europa en de landen aangesloten bij het GOS. Tevens wordt in dit rapport een aantal mogelijke toepassingen van het model gepresenteerd (het berekenen van CO_2 kostencurves voor verschillende zichtjaren, het gebruik van deze curves ter bepaling van het potentieel van het instrument "Joint Implementation" en een scenario voor de langere termijn (1990-2100).

1. Introduction

Energy combustion and industrial processes are major sources of greenhouse gas emissions (Houghton *et al.* 1992). Modifications in the global energy and industrial systems will play a key role in strategies to reduce greenhouse gases. In this paper we describe a model for developing long-term scenarios of regional energy use together with their expected greenhouse gas emissions. This model makes up a part of the "Energy-Industry Subsystem" of the IMAGE 2.1 model. In this paper validation of the model is presented against data from 1970 to 1990 for 3 world regions, and an application of the model in a scenario up to the year 2010.

The IMAGE 2.0 model is an integrated model of global climate change which includes three subsystems of models - "Energy-Industry", "Terrestrial Environment", and "Atmosphere-Ocean". Detailed information on the model can be found in Alcamo *et al.* (1994). The IMAGE 2.0 Energy-Economy model calculates use of energy by energy carrier for each region per sector . It enables the emission module to analyze greenhouse gas emission levels. A detailed description and application of this model can be found in De Vries *et al.* (1994). The major improvements on the IMAGE 2.0 Economy Energy Emission-module to be discussed in this paper are

- simulation of fuel substitution in secondary end-use, and
- improvement of the data base for the calibration of the 1970-1990 period

The regions considered in this report are Western and Eastern Europe and Common wealth of Independent States (CIS) conform to definitions used in Alcamo *et. al.*(1994).

First a description of the model will be given in chapter 2. In chapter 3 calibration c.q. validation of the model will be presented for the period 1970-1990 as well as scenario calculations for the 1990-2010 period. Sections 2 and 3 mainly focus on two sectors in three regions, because other sectors and regions are dealt with in a similar fashion. Chapter 4 presents applications of the current model. These include the calculation of investment costs of energy conservation; the use of investment cost functions to make a preliminary assessment of the global potential of the instrument Joint-Implementation, and estimates of energy consumption for a long-term reference scenario (to be described in Alcamo *et. al.*, 1995). The last section presents actions for future work on the IMAGE Economy-Energy module.

2. Model description

The conceptual design of the IMAGE 2.1 Energy-Economy model is an extension of the IMAGE 2.0 Energy-Economy model (de Vries *et. al.*, 1994). The goal of the Energy-Economy model is to allow the construction of energy use scenarios for world regions in a transparent and interactive way. It represents energy use as a chain of energy carrier handling processes from energy supply to end-use of energy: primary fuel production (fossil, renewable), transmission, energy transformation from primary fuels to secondary energy carriers (electric power generation and others such as oil refining), distribution, and final energy consumption in end-use sectors (industry, commercial, residential, transport and other); and finally the conversion in useful energy to provide energy services. A set of driving forces is distinguished in the model, i.e. activities that are assumed to correlate well with the demand for end-use energy functions. This demand is converted to the input of fossil fuels and other energy sources.

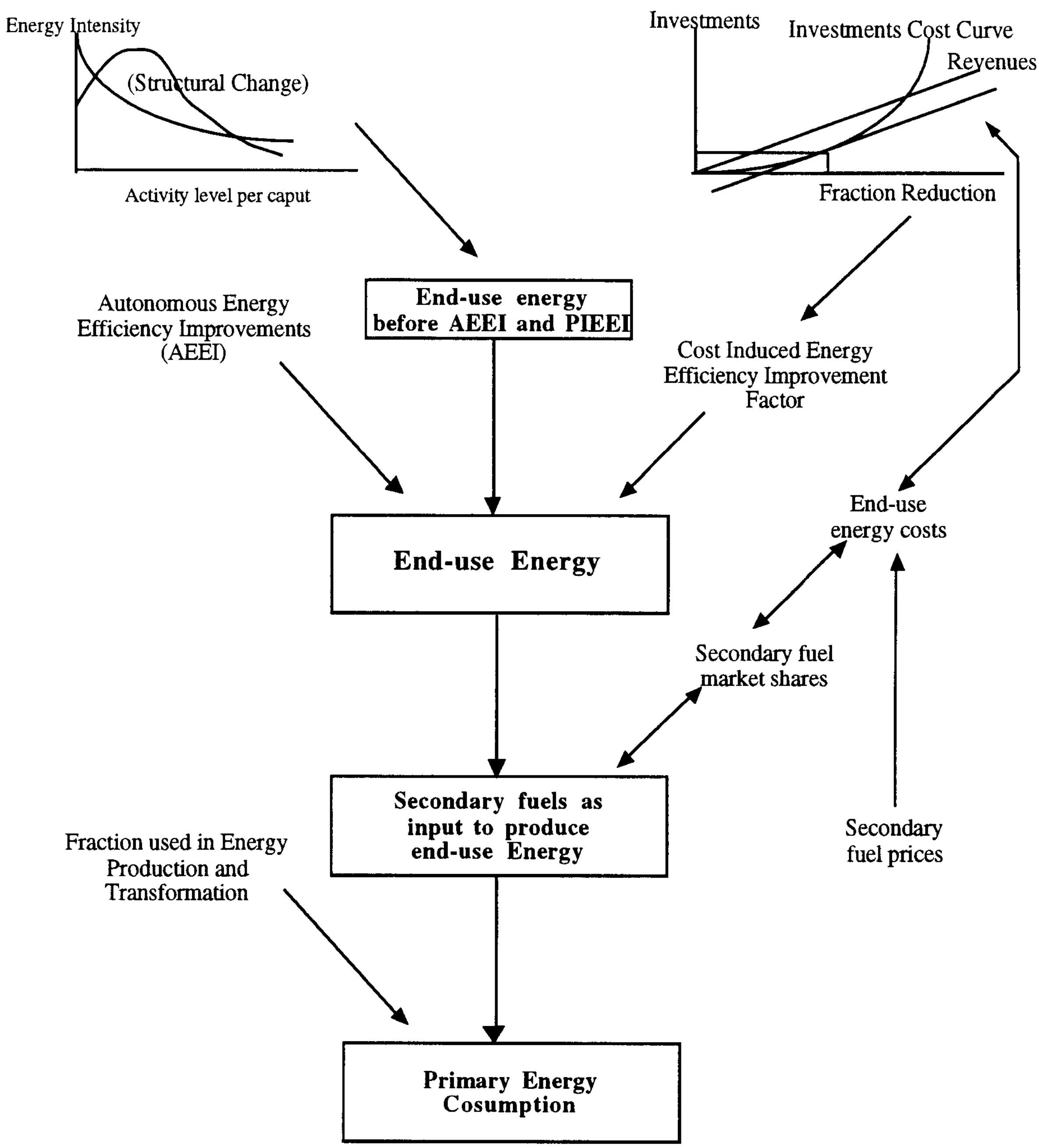
The focus on end-use energy has been applied earlier by other modellers (e.g. Johansson *et al.* 1989; Alcamo and De Vries, 1992; Schipper *et al.* 1992). A major advantage of this approach is that it focuses on the human needs for energy by examining how energy functions (services) are related to economic or human activity. It also enables the incorporation of "bottom-up" analyses. The approach also has limitations. There is the problem of having to estimate long term trends for phenomena with much shorter evolution cycles. Also, this approach requires data which are not or not yet available because in most statistical reports on energy only data on the use of primary and secondary fuels are presented. Finally, the trends assumed for input parameters are not easily checked for consistency because macro-economic calculations are not performed. The solution to this latter problem is to use well-defined and tested economic reference scenarios.

Figure 2.1 is a schematic representation of the IMAGE 2.1 Energy-Economy model. On the basis of sectoral driving forces the model generates demand for end-use energy for two types of energy functions: heat and electricity. This demand is based on prescribed relations between activity levels and energy intensities within a sector, as explained in section 2.1. The demand for end-use energy in this stage is calculated, omitting adjustments for autonomous energy efficiency improvements (AEEI) and price induced energy efficiency improvements (PIEEI) on end-use energy[1]. A two-vintage approach is used to simulate autonomous energy efficiency improvements with technological change not only based on an exogenous trend but

1 It should be noted that the thus calculated demand is a postulated non-observable quantity.

also on growth rates of activity levels. The inclusion of the effects of autonomous energy efficiency improvements is presented in section 2.2. Cost prices of the use of secondary energy carriers determine the fuel mix used within a sector (changes in investments and O&M costs are not considered). Section 2.3 deals with the derivation of the secondary fuel mix use, corrected for autonomous energy efficiency improvements (AEEI) and price induced energy efficiency improvements (PIEEI). The increase of the cost price of end-use energy is modelled as an incentive to save on the demand for end-use energy. Costs of end-use energy depend on the secondary fuel-mix and the corresponding set of prices of energy carriers used in this fuel-mix. Conservation measures to reduce the demand for end-use energy not only imposes higher costs but also generates revenues equal to the average end-use cost price per unit of energy times the reduction in units of end-use energy per year over the required payback time period. Maximizing the difference between these revenues and explicitly calculated additional costs (including annualized investments and operation and maintenance costs) over all possible conservation measures results in the "optimal" reduction of the energy intensity in a sector. In section 2.4 this methodology will be presented in further detail. Finally, calculations transforming secondary energy use in primary energy use (not illustrated in Figure 2.1) will be explained in section 2.5.

Figure 2.1: Simplified illustration of the IMAGE 2.1 Energy-Economy model as applied to two energy functions and five sectors



2.1 From activity to end-use energy

To simulate end-use energy for each sector, excluding autonomous energy efficiency improvements (AEEI, to be discussed in section 2.2) and price-induced energy efficiency improvements (PIEEI, to be discussed in section 2.4), the following equation is used in the model:

[1]

with, for any region r,

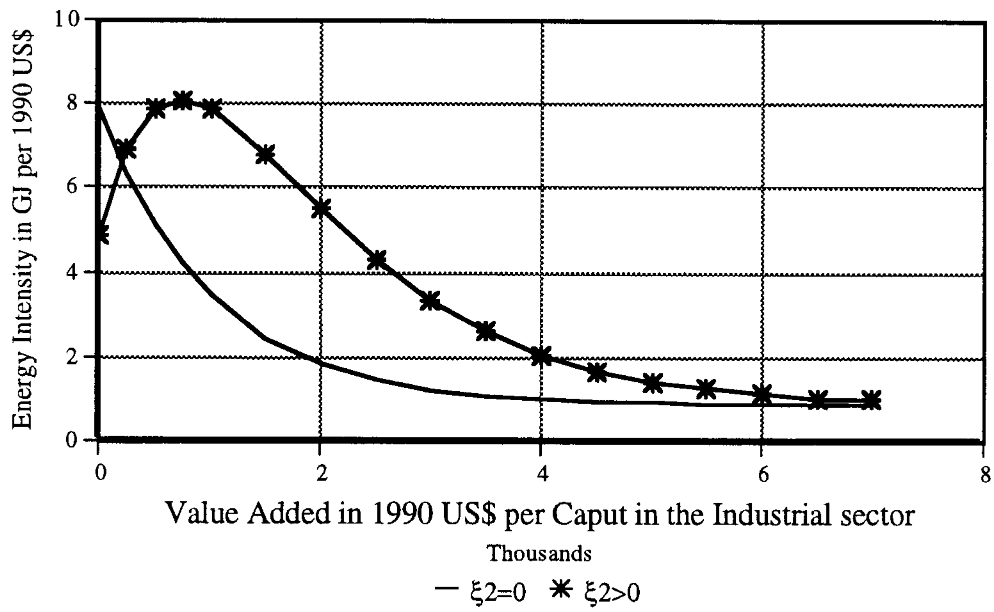
E	=	End-use energy demand without AEEI and PIEEI
A	=	Activity level
POP	=	Population within the region considered
	=	Lower bound of sectoral energy intensity (exogenous)
ξ_i	=	Parameters estimated on the basis of 1970-1990 regional data
t	=	Index of year
s	=	Index of sector (industry, transport, residential, commercial, other transformation)
j	=	Index of energy function (heat, electricity).

Equation [1] captures the structural change within the sector that leads to a change of the average end-use energy per unit of activity. In the industrial sector this reflects the increasing share of light industries; in the residential and commercial sector the shifts in life-style and office activities; in transport the effects of congestion and safety issues. Although it is known that these structural changes affect the energy intensity (see Schipper, 1992), it is difficult to find good empirical evidence. Equation [1] is chosen to allow sufficient transparency and flexibility in the calibration process and scenario construction. Defining the energy intensity $\varepsilon_t=(E_t/A_t) / (E_0/A_0)$ and the activity level per caput $\alpha=(A / POP)_t$ and omitting sector indices, equation [1] can be rewritten as:

[1a]

with the energy intensity exponentially declining to an assumed ε_∞. The value of ε_∞ is one of the scenario assumptions, to be based on a.o. on technology assessment studies. If structural change is only associated with declining energy intensities, the derivative must be increasing and smaller than zero. Since in all cases $\xi_3>0$, this implies that $\xi_2=0$. If structural change means, that as activity levels per caput increases higher energy intensities occur followed by a decline, this implies that $\xi_2>0$[1]. Both these cases are presented in Figure 2.2.

Figure 2.2: Illustration of Eqn. [1] for different set of parameters: energy intensity a function of the level of activity per caput in a sector before AEEI and PIEEI corrections. The first example with $\xi_2=0$ states that the energy intensity starts with 8 GJoules per unit VA and declines down to the lower bound of 0.9 PJoules per unit VA in the industrial sector as the VA per Caput increases. A second example is presented with a maximum at 500-1000 units VA per Caput followed by a decline down to the lower bound.



2.2 Autonomous Energy Efficiency Improvement (AEEI)

Studies like Molag *et.al.* (1979) point out that over the past five decades some sectors have been experiencing a decline in the price of energy carriers while at the same time the energy intensity measured in GJ per ton improved. This is due to what is called the Autonomous Energy Efficiency Improvements (AEEI). The rationale for this is that in the case of many, especially energy-intensive processes and related activities, people have been successfully looking for opportunities to use energy more productively, irrespective of changes in fuel

1 The derivative of equation [1a] is equals $\frac{d\varepsilon_t}{d\alpha_t}=\left(\xi_2-\xi_3\left(\xi_1+\xi_2\cdot\alpha_t\right)\right)\cdot e^{-\xi_3\alpha_t}$. The maximum is achieved at $\alpha^*=\frac{\xi_2-\xi_3\xi_1}{\xi_3\xi_2}$.

prices. In the Energy-Economy model (henceforth the EE model) it is assumed that end-use-energy demand decreases autonomously according to the following formula:

$$AE_{t,s,j} = E_{t,s,j} \cdot (1 - AEEI_{t,s}) \qquad [2]$$

with, for any region r,

AE = End-use energy with AEEI, but without price-induced energy efficiency improvements (PIEEI)

AEEI = Autonomous Energy Efficiency Improvement reduction factor of end-use energy (0< AEEI<1).

Historically, for many energy-intensive industrial products, the energy intensity dropped at rates between 0.5% and 1% per year. However, it is well understood that the underlying innovations are introduced mostly in new capital goods as retrofit options are often less effective and more expensive. The same probably holds for the non-industrialised sectors. Therefore, it is assumed in the model that the purely exogenous "technological progress" is only fully implemented in new capital goods. Hence, sectors growing at higher rates will experience higher penetration of new technologies and therefore also higher autonomous energy efficiency improvements.

In the model it is assumed that the AEEI-factor in equation [2] at year t is a function of the change of the average energy intensity in year t compared to year t-1:

$$AEEI_{t,s} = 1 - \left(\frac{AEI_{t,s}}{AEI_{t-1,s}} \right) \qquad [3]$$

with $AEI_{t,s}$ the average energy intensity at year t in sector s. This average energy intensity is the weighted average of the energy intensity of old and new capital equipment:

$$AEI_{t,s,j} = \frac{AEI_{t-1,s,j} \cdot OLDCAP_{t,s,j} + MEI_{t,s,j} \cdot NEWCAP_{t,s,j}}{OLDCAP_{t,s,j} + NEWCAP_{t,s,j}} \qquad [4]$$

with

MEI = Marginal Energy Intensity

OLDCAP = Index of old capital equipment at year t; $OLDCAP_{1970,s}$ is set equal to $CAP_{1970,s}$

NEWCAP = Index of new capital equipment.

The marginal energy intensity is calculated according to equation [5]:

$$MEI_{t,s,j} = \omega_{s,j} + \frac{t-1970}{20} \cdot \left(\omega_{s,j} - AEI_{1970,s,j}\right) \quad \text{for } t \in [1970,..,1990] \quad \textbf{[5a]}$$

$$MEI_{t,s,j} = MEI_{\infty,s,j} + \left(\omega_{s,j} - MEI_{\infty,s,j}\right) \cdot e^{-\frac{1}{\lambda_s} \cdot (t-1990)} \quad \text{for } t \in [1990,..,2100] \quad \textbf{[5b]}$$

with

MEI_{∞}	=	Lower bound of the marginal energy intensity
ω	=	parameter equal to the assumed marginal energy intensity in 1990
λ	=	Parameter describing the inverted exponential rate at which MEI declines.

The Marginal Energy Intensity (MEI) is only applied to capacities installed at the margin. Two formulations describe the MEI; the first refers to the 1970-1990 period and the second to the 1990-2010 period. The first formulation states that the MEI is equal to AEI in 1970 and declines linearly down to an assumed fixed percentage of the 1970 AEI. In the case of the 1990-2010 period, it is assumed that the MEI declines by an exponential function down to a region-and sector-specific lower bound. The rate at which the marginal energy intensity is assumed to decline is sector dependent. By using this formulation the purpose of calibration of the model to the 1970-1990 period and scenario construction[1] is served.

The capital stock is the sum of old and new capital equipment. The total capital stock in a sector is assumed to grow at the same rate as the activity within that sector:

$$CAP_{t,s} = CAP_{t-1,s} \cdot \left(\frac{A_{t,s}}{A_{t-1,s}}\right) \quad \textbf{[6]}$$

with $CAP_{t,s}$ the index of capacity required at year t ($CAP_{1970,s}$ is set to 100). Old and new capital equipment is calculated from equations [7a] and [7b]:

[1] Central and Eastern European countries (CEE) which are in transition towards market economies, experience energy intensities that are 100-200% higher than in Western European countries. It may be expected that there will be a sharp decline in sectoral energy intensities (see Environmental Action Programme for Central and Eastern Europe, 1993 and Bollen et. al., 1993). Lower energy intensities in CEE are a result of a decline of production combined with early scrapping of old and relatively inefficient capital equipment and harmonization of energy prices to world market levels. To simulate these expert judgements, which are difficult to quantify, a non-continuous decline of the marginal energy intensity over time can be introduced for newly installed capital equipment. In this model a two vintage approach is used in which capital equipment is characterized by energy intensities. In CEE countries the industrial sector may experience a sharp fall followed by an increase in production. This implies a fast penetration of capital equipment with low energy intensities and hence a relatively fast decline of the overall energy intensity.

$$\mathrm{OLDCAP}_{t,s} = \min\left\{\mathrm{OLDCAP}_{t-1,s}\cdot\left(1-\mathrm{scr}_s\right)+\mathrm{NEWCAP}_{t-1,s},\mathrm{CAP}_{t,s}\right\} \quad [7a]$$

with scr_s is the scrapping rate in sector s and

$$\mathrm{NEWCAP}_{t,s} = \mathrm{CAP}_{t,s} - \mathrm{OLDCAP}_{t,s} \quad [7b]$$

with $NEWCAP_t$ the index of new capital equipment required at time t. This implies a two vintage approach[1]. Old and new installed capacities are scrapped at the same rate. In reality this does not hold but additional information to follow a more realistic approach is hardly available. The capital stock may in reality change at a rate different from the activity level due to e.g. improvements of productivity of capital; this has not been taken into account.

2.3 Market shares for secondary energy carriers: cost-driven fuel substitution

End-use energy is provided by a variety of secondary energy carriers, the conversion of which requires investment goods and results in conversion losses. The resulting secondary energy use of an energy carrier f is based on end-use energy (including AEEI described in paragraph 2.2 and PIEEI to be discussed in section 2.4) multiplied by its weighted market share and the energy conversion factor.

In the case of the energy function "heat" the market share α of an energy carrier f of total secondary energy use on newly installed capacities is modelled by a MultiNomial Logit (MNL)-function (see e.g. Moxnes, 1989):

$$\alpha_{f,t,s,h} = \alpha_{f,t-1,s,h}\cdot\frac{\mathrm{OLDCAP}_{t,s,j}}{\mathrm{CAP}_{t,s,j}} + \frac{\left(c\cdot\rho\right)_{f,t,s,h}^{-\theta_s}}{\sum_j \left(c\cdot\rho\right)_{j,t,s,h}^{-\theta_s}}\cdot\frac{\mathrm{NEWCAP}_{t,s,j}}{\mathrm{CAP}_{t,s,j}} \quad [8]$$

with

1 More vintages are not distinguished in the model since efforts to obtain the amount of data and additional assumptions required to fill this system do not result in significant differences. This especially holds for simulations with longer time horizons.

α	=	Market share of energy carrier f in year t for the energy function heat
c	=	Secondary fuel price (see Appendix A)
ρ	=	Premium factor of secondary energy carrier
θ	=	Price cross-substitution elasticity among secondary energy carriers on newly installed capacities
f	=	Index of secondary fueltype (coal, oil, gas, nuclear power, renewables, fuelwood, biomass)
h	=	Index of energy function: in this case heat.

Equation [8], states that the overall market share of a particular energy carrier depends on the weighted market share of old capital equipment and newly installed capital equipment. It assumes that for newly installed capital equipment the share of an energy carrier f at time t in sector s for energy function h depends on the costs of using that energy carrier. Also it includes a premium factor (fuel and sector specific) which accounts for e.g. strategic and/or environmental considerations, which are not reflected in (average) cost prices(below this is explained in further detail).

Clarke and Edmonds (1992) found that energy users, facing a set of energy technologies following a Weibull cost price distribution function, will choose market shares based on the MNL-function. The E-E model uses the MNL-function only on newly installed capital equipment. Therefore , in the E-E model case, the value of the cross-price-substitution elasticity can be expected to be higher because at the margin of the capital stock substitution between technologies (or the use of the different energy carriers) will depend much more on fuel price differences. It is assumed that all technologies are demanded and supplied in a competitive market. Hence, there are no long-term costs involved[1].

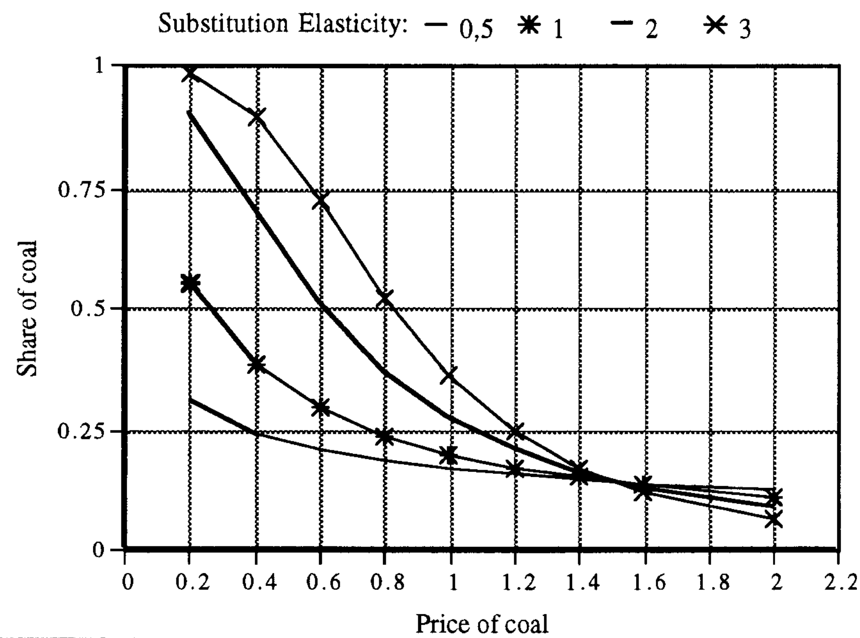
Fuel prices are multiplied by a premium factor in equation [8] to account for the fact that market shares cannot only be explained by fuel price differences between energy carriers. These new cost price factors can be interpreted as shadow prices. As the premium factor decreases the energy carrier considered gets a higher (marginal) market share. In the case of gas for electric power generation Moxnes (1989) finds a declining premium factor over time. For coal it was found that the premium factor was smaller than one and increased from 1970 to 1990. This is due to non-market advantages of coal over other energy carriers for large-

1 In order to assess the potential of the instrument Joint Implementation one has to bear in mind that fuel-switching is therefore not an option.

scale electric power generation, which had been supported explicitly by the government and to the fact that natural gas had attractive prospects in some regions despite its initial high price and infrastructural limitations. In this model premium factors have been calibrated; in the post-1990 period the 1986-1990 averages are used.

As an illustration of the MNL-function Figure 2.3 shows the share of coal in the secondary energy use as a function of the relative price of coal compared to the other energy carriers. The steepness of the curve is determined by the cross-price-substitution elasticity between the different energy carriers. Lower values of the substitution elasticity result in lower equilibrium market shares for coal (see Eqn. [8]). In the MNL- formulation, if prices of secondary energy carriers are equal, each of them has a market share equal to 1/n (at the coal price 1.5 in Figure 2.3) In a dynamic context, a change in relative prices will result in a change in equilibrium market shares in new capital, which in the EE model shows up with a delay depending on the rate of change of the activity level (see Eqn. [8]). The underlying assumption is that a retrofit fuel switch is not a fully realistic option, especially in the case of severe price fluctuations (1979-1986 period). This is another reason for finding non-zero premium factors for the 1970-1990 calibration.

Figure 2.3 Share of coal on newly installed equipment as a function of the relative price of coal in the case of a substitution elasticity of 0.5, 1, 2 and 3 %; prices of all other energy carriers are set equal to 1.5 in this example.



For the energy function "electricity" only one secondary carrier is taken into account: electricity. This implies that heat-electricity substitution is not explicitly considered and has to be incorporated through the activity-demand relation discussed previously. In some cases e.g.

scenarios this may be an important issue e.g. with large-scale penetration of electric heating or electric transport. For electricity generation, exogenously determined market shares have been used because market shares not only depend on relative prices of the different energy carriers, but also on other determinants not included in the model (see de Vries *et.al.,* 1994). For greater flexibility in model applications, the market shares of energy carriers can also be exogenously specified.

2.4 Increase of energy productivity due to rising prices of secondary energy carriers: Price-Induced Energy Efficiency Improvement

In paragraph 2.3 it has been explained how market shares of secondary energy carriers are determined within the model. Market shares, as can be seen from Eqn. [8], depend on the relative prices of the different energy carriers distinguished within the model. Another factor in the determination of these shares is the relative amount of old compared to new capital. Costs per unit of end-use energy are calculated for each sector by using these market shares in combination with exogenously set conversion efficiencies. In the next year, this will then affect (marginal) market shares.

The only factor not included up till now in the model are investments in energy conservation in the existing capital stock. In this model such investments are defined as retrofit measures which are driven by changes in average end-use energy cost. These measures improve the energy productivity of the existing capital stock of machinery, houses, offices, cars, etc. They do not refer to the capital stock related to the conversion of secondary to end-use energy, e.g. coal-, oil- or gas-fired boilers. This implies that exogenously set conversion efficiencies for these capital stocks are not based on cost considerations. Figure 2.4 is an illustration of the capital stock categories as defined in the Energy-Economy model, although none of the distinctions can be sharp.

These elements are modelled in the following way. At any moment in time secondary energy is calculated as:

$$S_{f,t,s,j} = AE_{t,s,j} \cdot \left(\frac{\alpha}{\varepsilon}\right)_{f,t,s,j} \cdot \left(1 - \beta_{t,s,j}\right) \qquad [9]$$

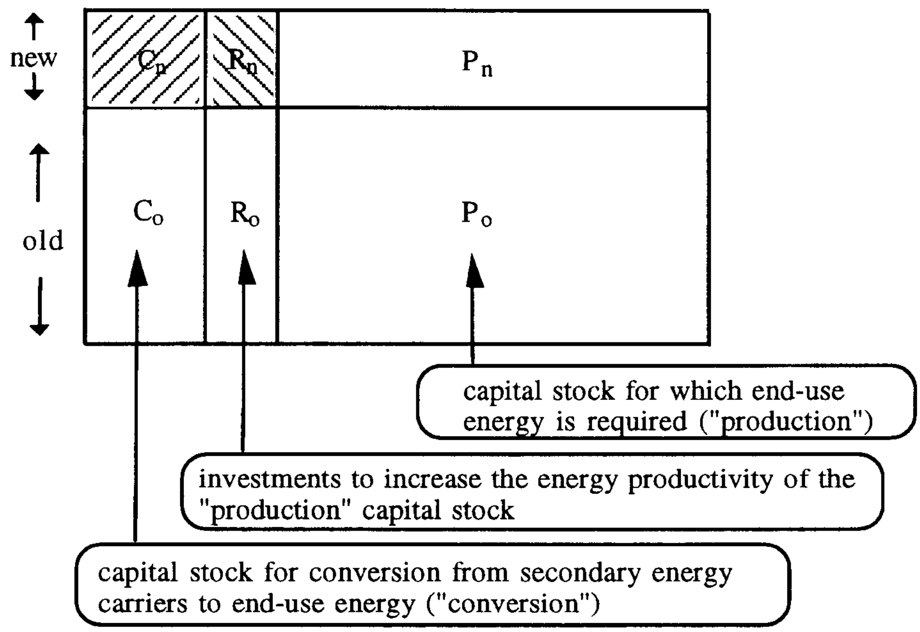
with AE, f, α and ε as defined before and, for any region r,

S = Secondary use of energy of fuel type f

β = End-use energy savings factor based on end-use energy cost

The market shares are determined by equation [8] and the conversion efficiencies are exogenous input variables to the model. The factor $\beta_{t,s,j}$ is equal to the fraction with which the energy-intensity is reduced due to prevailing cost prices per unit of end-use energy.

Figure 2.4: Sectoral capital stock divided into old capital and new capital. The indexed values of P_n and P_o are used for autonomous decrease of the energy intensity and for market shares of secondary energy carriers. The values of R_n and R_o are calculated from energy conservation cost curves. The values of C_n and C_o are represents the capital stock required to transform secondary energy to end-use energy.



The reduction factor $\beta_{t,s,j}$ in Eqn [9] represents the outcome of numerous decisions to maximize the difference between investment costs and revenues per unit of end-use energy. These investments are related to revenues by way of the energy conservation curve IC= I(β) which represents the cumulative investments as a function of the fraction reduction in energy intensity. A variety of such curves have been published in the literature over the past 5-10 years (de Vries, 1986, Blok *et.al.*, 1990). To model the general characteristics of increasing marginal investment costs to reduce one additional unit of energy and the decline in investment costs over time as a result of learning, scale and innovation dynamics, the following formula is used:

$$IC_{t,s,j} = \phi_{s,j} \cdot \prod_{j=t_o}^{t} \left(1-\alpha_j\right) \cdot \left(\frac{1}{B_{s,j} - \beta_{t,s,j}} - \frac{1}{B_{s,j}} - \frac{\beta_{t,s,j}}{B_{s,j}^2} \right) \qquad [10]$$

with

IC	=	Investments required to reduce energy intensity with a factor β
B	=	Exogenously set parameter; maximum attainable ß

Rewriting Eqn. [10] by putting $\beta=\zeta*B$ and $t=t_0$ results in:

$$IC_{t,s,j}=\frac{\phi_{s,j}}{B_{s,j}}\cdot\left(\frac{\zeta^2_{t,s,j}}{1-\zeta_{t,s,j}}\right) \qquad \textbf{[10a]}$$

If $\zeta_{t,s,j}\rightarrow 1$ then $IC_{t,s,j}\rightarrow\infty$ and if $\zeta_{t,s,j}\rightarrow 0$ then $IC_{t,s,j}\rightarrow 0$. The factor $\phi_{s,j} / B_{s,j}$ can be interpreted as the total investment costs associated with a reduction of the energy intensity with a factor $\beta_{t,s,j}/B_{s,j}=(\sqrt{5}-1)/2\approx 0.55$ derived from $\zeta^2_{t,s,j}/\left(1-\zeta_{t,s,j}\right)=1$. For $t>t_0$ this value declines inversely proportional.

In the IMAGE 2.1 model energy conservation investments to reduce the end-use energy intensity are based on the maximization of the difference between investment costs (see Eqn. [10]) and revenues modelled in the following way:

$$IR_{t,s,j}=P_s\cdot\beta_{t,s,j}\cdot\sum_f\left(c_{f,t-\Delta t,s,j}\cdot\frac{\alpha_{f,t,s,j}}{\varepsilon_{f,t,s,j}}\right) \qquad \textbf{[11]}$$

with

IR	=	Investment revenues due reduction of the energy intensity with a factor β
P	=	Required payback time
Δt	=	Perception lag
c	=	costs of end-use energy (1990 US$ per unit of end-use energy)

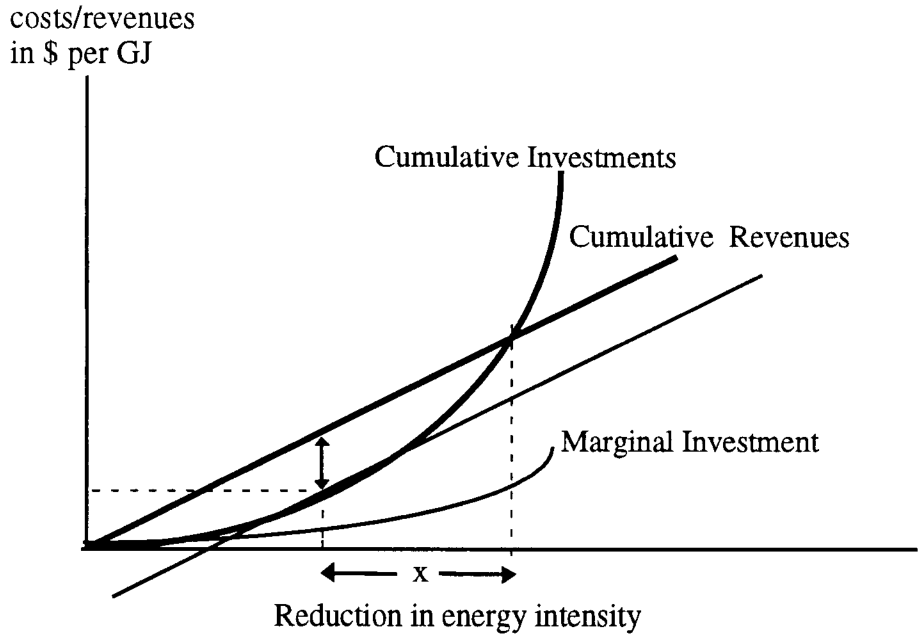
This equation shows that a perception lag of Δt years is assumed to account for the delayed response of energy users in implementing energy conservation measures when the costs of end-use energy rises. In appendix A the derivation of the costs per unit end-use energy is explained in further detail. The maximization process[1] is illustrated in Figure 2.5.

---

[1] The derivative (or the marginal investment curve) of equation [10] is equal to $\frac{dI_t}{d\beta_t}=\Theta_t\cdot\left(\frac{1}{\left(B-\beta_t\right)^2}-\frac{1}{B^2}\right)$ with $\Theta_t=\phi\cdot\prod_{j=t_0}^{t}\left(1-\alpha_j\right)$. This function is zero for β_t equals zero. Optimal β^*_t can be calculated by setting the marginal investment cost curve equal to the marginal revenue function.

This results in condition for $\beta^*_{t,s,j}$ $\beta^*_t= B-\left(\frac{1}{B^2}+\frac{c_{t-\Delta t}\cdot P}{\Theta}\right)^{-1/2}$ where $c_t=\sum_f c_{f,t}\cdot\frac{\alpha_{f,t}}{\varepsilon_{f,t}}$. Fixing the parameters B, ϕ, α and δ this equation shows that β_t increases as the average costs of useful energy increases or as time evolves (autonomous decline of the investment cost function).

Figure 2.5: Cumulative investments and revenues are represented by the bold lines; optimal reduction of the energy intensity is equal to that amount where the difference of the curves is maximal. This is equal to the statement that optimal reduction is equal to that value where the marginal cost is equal to the marginal revenues. If energy users choose to reduce even further than β^*, net revenues will decrease and even fall below zero in the case of reductions beyond $\beta^* + x$.



In the Energy-Economy model it is assumed that the increase of β is irreversible i.e. when end-use energy costs per unit of energy decline the energy intensity is maintained at its previous level. This is not wholly realistic, especially not in the case of behaviourial dynamics being an important determinant of energy use. Nevertheless this assumption may be adequate in dealing with the majority of energy conservation measures like better insulation of ovens, windows, improved pump and compressor performance and management etc. Ironically, with falling end-use energy costs and rising incomes, the energy intensity may increase precisely because the higher energy efficiency of capital goods induces more demand. This may be caused by a consumption of goods requiring more end-use energy or less careful behaviour of energy users.

Two points deserve attention. First, the choice of maximization of the difference of costs and revenues implies that users invest up to an economically optimal level of reduction of the energy intensity. Still there will remain conservation measures that generate revenues when applied by energy users. But they will decrease total revenues due to additional energy conservation. In this model targets of specific government action, e.g. subsidies which are aimed at energy conservation, can be translated in investments in dollars per unit of end-use energy per year. Then, the additional reduction in the energy intensity can be determined from the cumulative net investment function. A second point is the autonomous decline of the costs per unit of end-use energy of conservation measures, as indicated by $(1-\alpha)$ in Eqn. [10]. In the real world, once energy conservation measures are penetrating the market , their costs tend to decrease due to learning, scale and innovation. These cost decreases have been set exogenously and can be adjusted by the parameter δ, representing another kind of government policy, e.g. R&D -projects. The result is that high investment costs of conservation measures can be avoided over time.

2.5 Secondary energy use to primary energy use

Losses occur in the process of transforming primary into secondary energy carriers. These losses have been modelled as a fixed fraction of total secondary energy use per energy carrier. Also district heating with its high conversion efficiency is incorporated in these fractions. Heat and electricity demand are corrected for end-use energy generated by district heating; the use of primary energy attributed to district heating is included in the conversion losses.

2.6 Derivation of cost curves

This section presents graphs of regional CO_2 abatement cost curves based on the end-use energy conservation investment cost curves per region, and per sector and energy function. A more detailed description as well as the mathematical expression that follow the presented procedure can be found in appendix B.

The following steps are used to derive cost curves (see Figure 2.6):

(1) transform the energy cost curve (see Eqn. [10]) in a CO_2 abatement cost curve with fuel-specific emission coefficients;

(2) transform the 1970 investment cost curve from step (1) in a curve for year 1970+t (energy efficiency measures taken in the period [1970, 1970+t] have to be omitted and the revenues generated in that period due to energy efficiency measures have to be included in the determination of costs for the remaining conservation measures). This results in the cumulative cost curve for year 1970+t;

(3) derive the derivative of the function generated by step (2). This results in the marginal cost curve for year 1970+t;

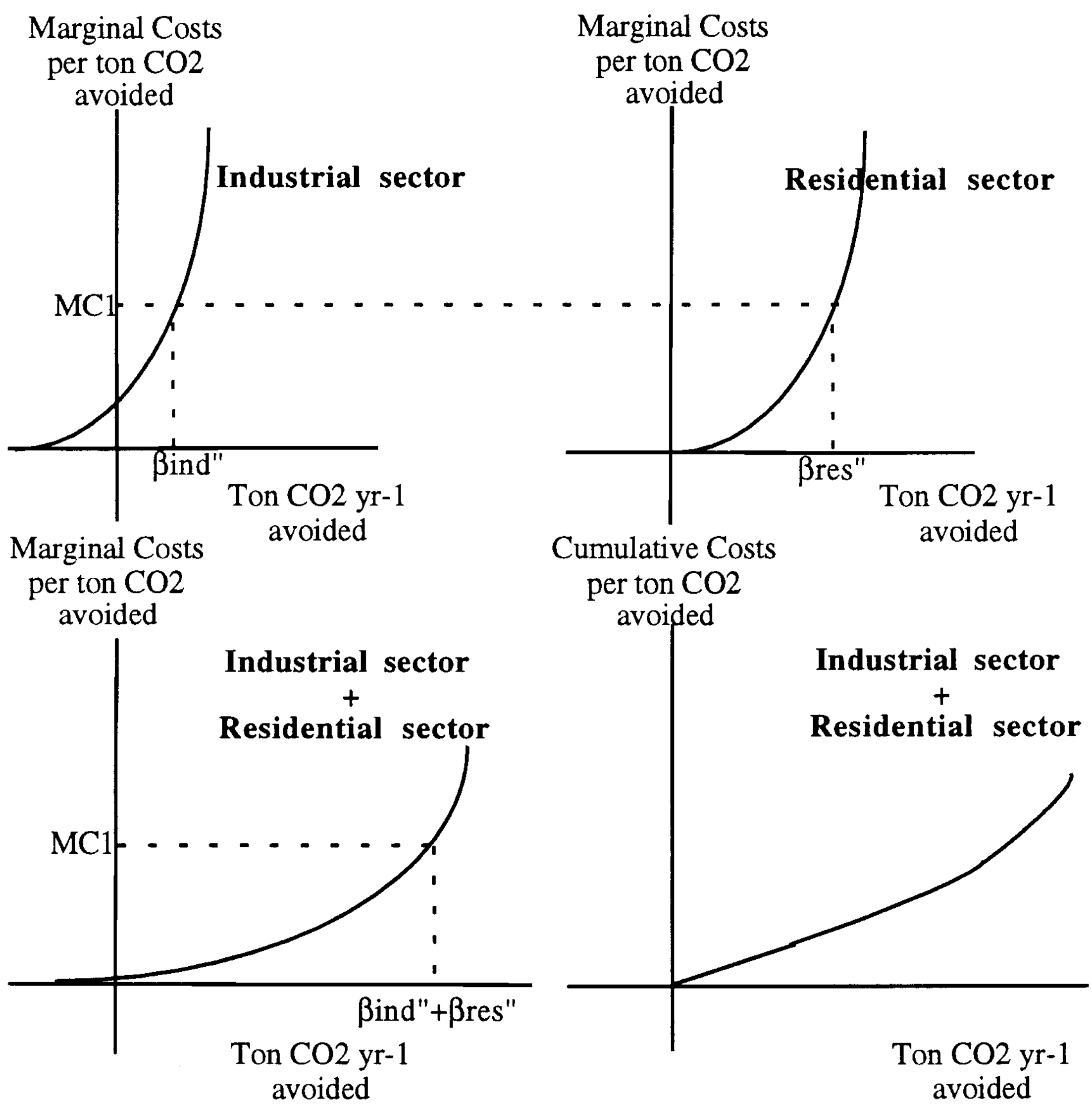
(4) invert the function that resulted from step (3). This results in the inverse of the marginal cost curve for year t;

(5) aggregate the functions for **all sectors and energy functions** resulted from step (4) for each potential marginal costs. This gives the aggregated inverse of the marginal CO_2 abatement cost curve for year 1970+t;

(6) derive the cumulative CO_2 cost function.

This procedure is illustrated by an example of a region with two sectors and one energy function.

Figure 2.6: Curves for the industrial and residential sector presented at the top are the marginal investments per ton CO_2 avoided as a function of tonnes of CO_2 avoided. At the bottom the aggregated marginal investment function and cumulative aggregated investment function is presented.



Steps 1 till 4 result in the curve presented in the top of Figure 2.6 on the left side and shows that if the industrial sector is willing to invest at the most MC1 dollars per ton CO_2 removed,

βind" ton CO_2.yr^{-1} will actually be removed. If the residential sector is willing to invest at the most MC1 dollars per ton CO_2 removed, βres" ton CO_2.yr^{-1} will actually be removed. The left curve at the lower part of Figure 2.6 results from step 5 and shows the results of the aggregated inverted marginal investment cost curve. The last curve presented in Figure 2.6 shows the aggregated cumulative investment cost curve that is derived from the marginal investment cost curve.

3. Simulation of the period 1970-1990

In this chapter it will be explained how the E-E model has been calibrated on the basis of 1970-1990 data for the 13 IMAGE 2 regions. In general the procedure follows the steps in Figure 1:

(1) Calculate end-use energy demand from historical activity levels according to Eqn. [1];

(2) Recalculate end-use energy demand taking into account AEEI and PIEEI, using historical prices of secondary energy carriers determining market shares;

(3) Recalculate market shares through adjustment of premium factors for 1985-1990 period

(4) Calculate the resulting use of secondary energy use and compare it with historical data. If there are any major discrepancies return to step 1 and change parameter assumptions accordingly.

It should be noted that by using this procedure there is no unique "solution" for the various model parameters. As was discussed in de Vries et. al. (1994), there are large differences among the different sectors. Not all the parameters can be initialized by values which can be found in the literature. Hence, the procedure only changes a subset of the complete parameter set of the model. By going through the procedure, in some iterations parameters referring to the first step of the procedure will be altered, depending on the magnitude of the error that the model generates. But, e.g. when end-use energy is fairly matched, then only parameters like the substitution elasticity in the MNL function or some premium factors are changed to decrease the difference between the historical and the calculated set of market shares.

In this chapter results for the 1970-1990 will be presented only for three regions and two sectors. The regions consist of OECD Europe, the CIS region and Eastern Europe and the sectors include the industrial and residential sector. The first two regions will be considered because

(1) they appear frequently on the ordered list of the twenty largest sectors in terms of end-use energy of the world (see Table 3.1) and account for about 25% of the World's total demand for end-use energy and

(2) they face quite different near-term future circumstances and consequently there are differences in scenario assumptions for the two regions for the 1990-2010 period.

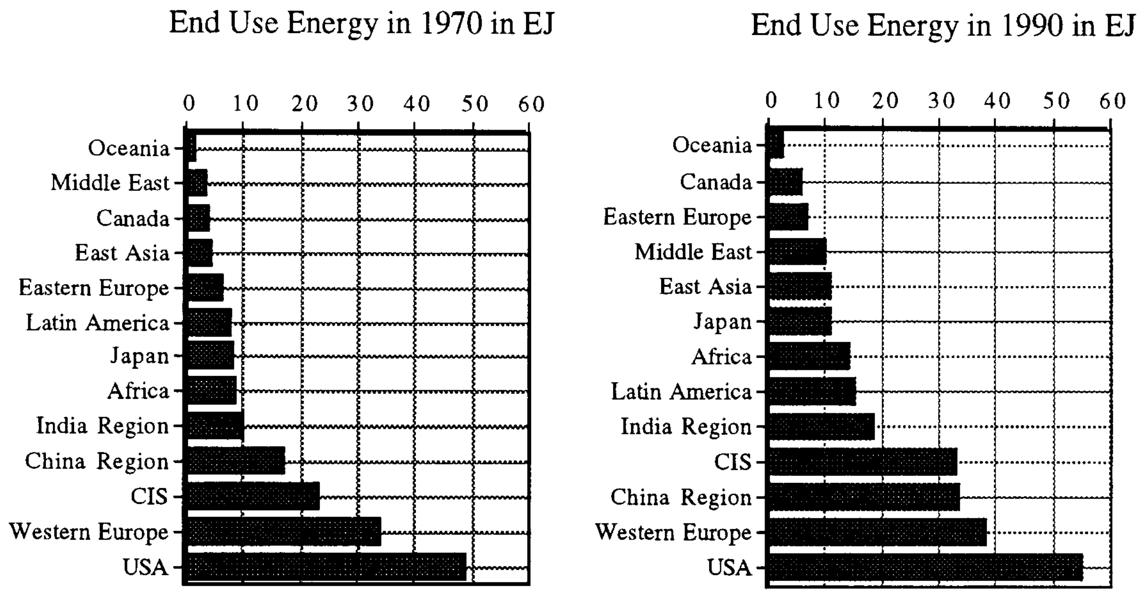
Crucial parameters of the model for OECD Europe, the CIS region and Eastern Europe will be reported in this chapter and for other regions in Appendix C.

In Figure 3.1 total end-use energy is presented for all regions in 1970 and 1990. A word of caution is required because end-use energy demand only includes **commercial fuels**. In many of the less developed regions, **traditional fuels** play a large role (see Hall *et. al.*, 1994) and their inclusion could significantly change the order of the list in Figure 3.1. These data **are accounted for** in the IMAGE model[1].

It can be seen that the largest share of the global energy consumption is in the USA and OECD Europe. End-use energy demand in China + C.P. Asia and the CIS has increased significantly in twenty years. In the 1970-1990 period the demand for end-use energy showed the largest increase in the Middle East (290%), East Asia (225%) and China+C.P.Asia (90%).

[1] see data for 1990 in Hall *et al.* (1994), for the other years the growth of the demand for other solid fuels in OECD countries from the IEA statistics are used to calculate the demand for traditional fuelwood.For most non-OECD countries vegetable fuels as reported in IEA statistics are used to extrapolate the traditional fuelwood demand and for those countries for which missing values are reported, population growth has been used to generate fuelwood demand.

Figure 3.1: End-use energy as supplied by commercial fuels, incl. electricity in 1970 and 1990 for the IMAGE-regions



Source: Data from IEA as reported in Toet and De Vries (1994).

The EE model is defined for 13 regions, five sectors and two energy functions. Therefore 130 cases (13 regions * 5 sectors * 2 energy functions = 130) have to be investigated. In Table 3.1 the largest twenty out of 130 cases are presented for the year 1990. The aggregate of these twenty cases account for 70% and 64% in 1970 resp. 1990 of total world energy demand.

The relative importance of the different sectors / energy functions changed between 1970 and 1990, e.g. heat demand in the residential sector in China + C.P.Asia and heat demand in the industrial sector in Latin America, are among the twenty largest cases in 1990 but not in 1970. As other examples, heat demand in the other sectors in China and the heat demand in the industrial sector in Eastern Europe were on the list of the largest end-use energy sectors in 1970 whereas they do not appear on the 1990 list.

Table 3.1: Ranking of the largest sectors and energy functions of end-use energy demand. This Table presents the share of these cases compared to the worlds total demand for end-use energy in 1970 (column share 1970) and in 1990 (column share 1990) and the score of these items compared to the twenty largest cases in 1970 (column ranking 1970). Note that electricity refers to end-use energy, i.e. not accounting for conversion losses.

IMAGE REGION	SECTOR	energy function	Ranking 1970	Cumul. Share 1970	Ranking 1990	Cumul. Share 1990
USA	TRANSPORT	heat	1	11%	1	10%
CHINA+C.P.ASIA	INDUSTRY	heat	19	12%	2	17%
OECD EUROPE	TRANSPORT	heat	6	17%	3	23%
CIS	INDUSTRY	heat	4	23%	4	28%
USA	INDUSTRY	heat	2	32%	5	34%
OECD EUROPE	INDUSTRY	heat	3	40%	6	37%
OECD EUROPE	RESIDENTIAL	heat	7	45%	7	40%
CIS	TRANSPORT	heat	10	47%	8	43%
USA	RESIDENTIAL	heat	5	53%	9	46%
LATIN AMERICA	TRANSPORT	heat	14	55%	10	48%
CHINA+C.P.ASIA	RESIDENTIAL	heat	100	55%	11	50%
USA	COMMERCIAL	heat	9	58%	12	52%
CIS	OTHERS	heat	13	60%	13	53%
USA	RESIDENTIAL	electricity	20	61%	14	55%
LATIN AMERICA	INDUSTRY	heat	25	62%	15	56%
CIS	COMMERCIAL	heat	15	64%	16	58%
JAPAN	INDUSTRY	heat	11	66%	17	60%
MIDDLE EAST	TRANSPORT	heat	22	67%	18	61%
OECD EUROPE	INDUSTRY	electricity	18	68%	19	63%
USA	INDUSTRY	electricity	17	70%	20	64%

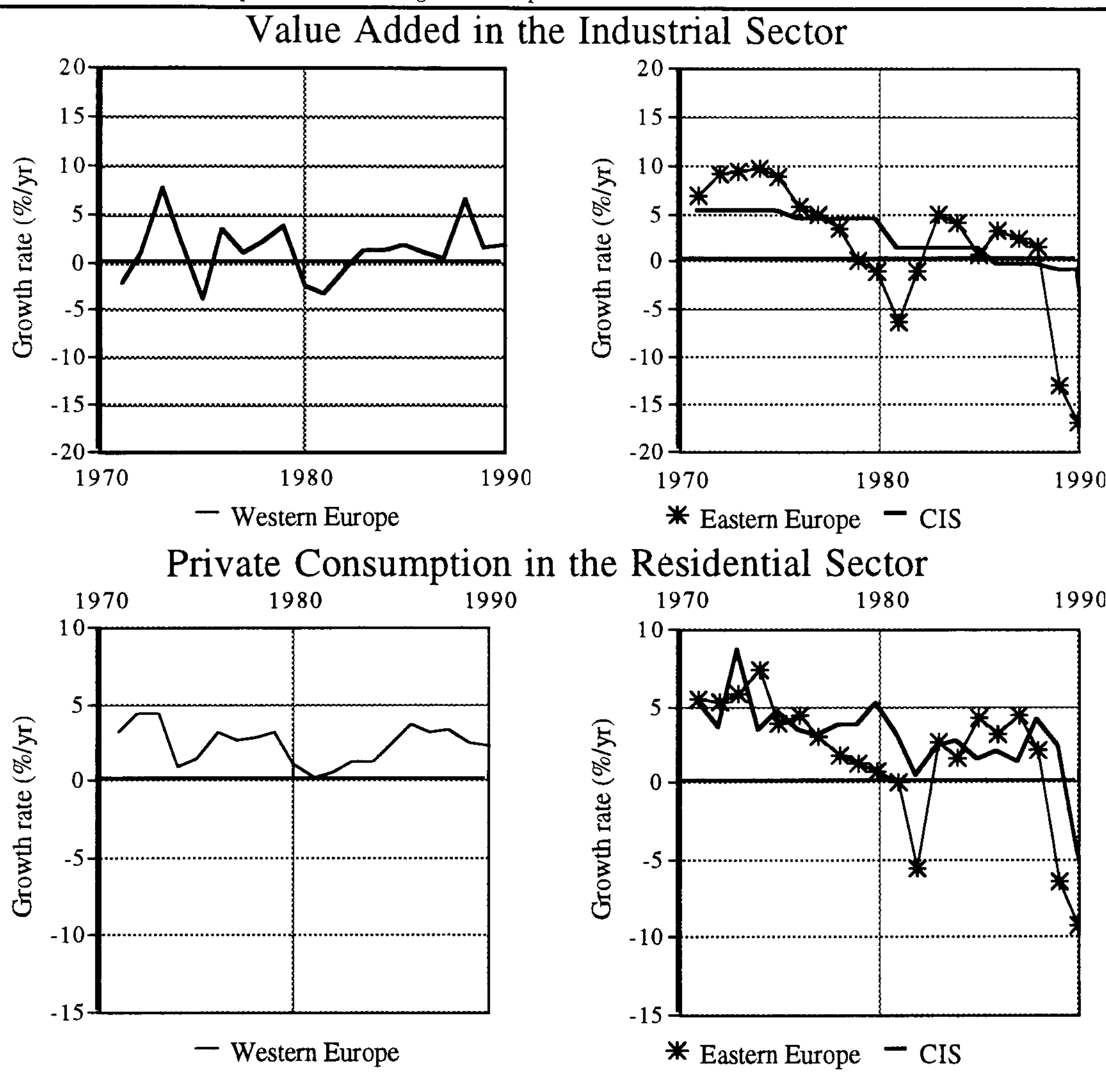
Source: Toet and De Vries (1994).

In section 3.1 activity levels as well as end-use energy demand (before AEEI and PIEEI) and the underlying parameters for the model calculations are presented. Section 3.2 explains the AEEI factors used within the model. In section 3.3 market shares and its driving forces will be described and explained. In section 3.4 the parameters of the investment functions are explained. In section 3.4 the subject of investment cost functions will be dealt with; the calibration and the dynamic aspects as well as some interregional differences. Finally, in section 3.5 the overall explanatory power of the E-E model will be shown by illustrations of developments of end-use energy demand in some regions.

3.1 Sectoral activity levels and calculated end-use energy demand before AEEI and PIEEI

The main driving forces that serve as input to the EE model for the calculations covering the period 1970-1990 are sectoral activity levels and the prices of secondary energy carrier. In appendix D these driving forces are summarized for the following regions: (1) OECD Europe, (2) Eastern Europe and (3) CIS. The collection of data for the 1970-1990 period is discussed and presented for **all** regions in Toet and De Vries (1994) and the HYDE report (see Klein Goldewijk and Battjes *et.al.*, 1995).

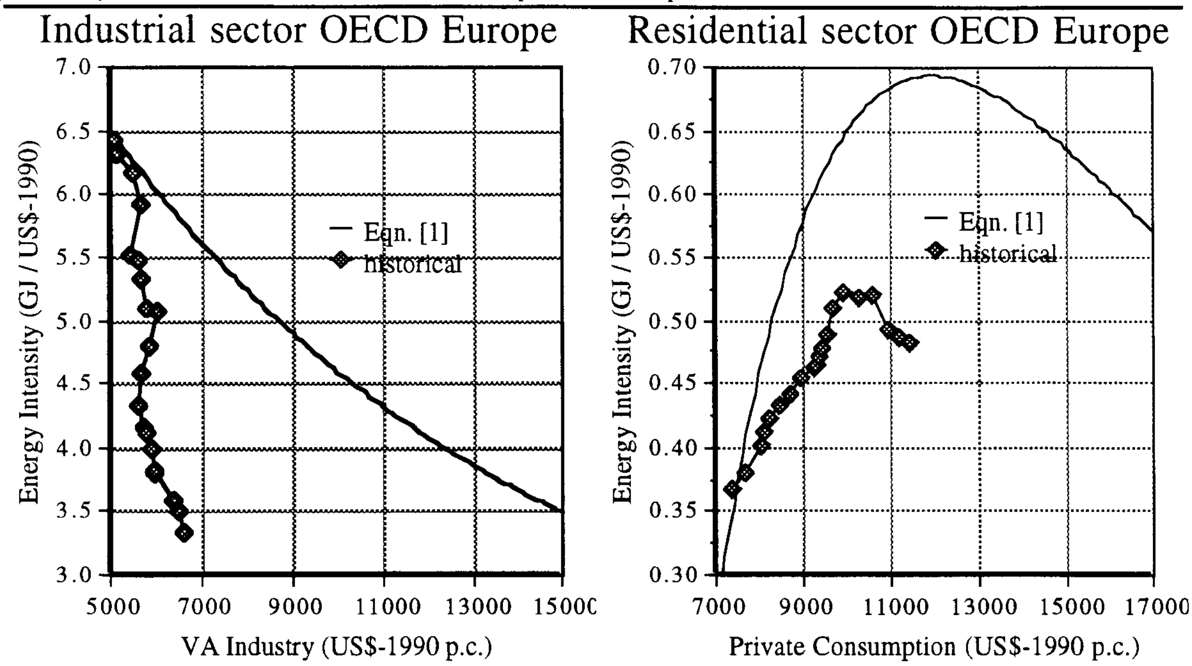
Figures 3.2 a-d: Growth rates of VA in constant prices in the industrial sector in Western and Eastern Europe and the CIS region in the period 1970-1990. Growth rates of private consumption in constant prices in the residential sector in Western and Eastern Europe and the CIS region in the period 1970-1990.



Source: Hyde (1995) for the 1970-1990 data and Bollen *et.al.* (1993) and World Bank (1993) for the 1990-2010 data.

An illustration of the growth rates of the industrial sector is presented in Figures 3.2 a-b for the period 1970-1990 in Western and Eastern Europe and the CIS region. As can be seen from Figure 3.2a the growth of the industrial sector in OECD Europe is relatively stable compared to Eastern Europe and the CIS region. At the end of the 1985-1990 period, the decline of the industrial sector started first in Eastern Europe (Figure 3.2b). In this period restructuring of the industrial sector occurred. Also it can be seen from Figure 3.2c and 3.2d that the fall of the growth rates of private consumption is less severe than the fall of VA of the industrial sector. This may be caused by the fact that the large parts of industrial sector face competition from industries abroad, whereas personal consumption not only depends on the industrial sector but also relies on sheltered sectors like the agricultural and commercial sector.

*Figures 3.3 a-b: Energy intensities (**before AEEI and PIEEI**) according to Eqn. [1] for OECD Europe as a function of value added in the industrial sector and private consumption in the residential sector*



Source: Toet and De Vries (1994).

End-use energy demand is calculated in the model by examination of cross-country data on the energy-intensity vs. activity per caput. Figure 3.3 shows the results for OECD Europe. Previous analysis of the energy-GDP/cap relationship (see de Vries *et. al.*, 1994) indicated the importance of structural change at this aggregate level; it pointed out a remarkable difference in the height, not the shape of this relationship over time among the various regions/sectors of the world.

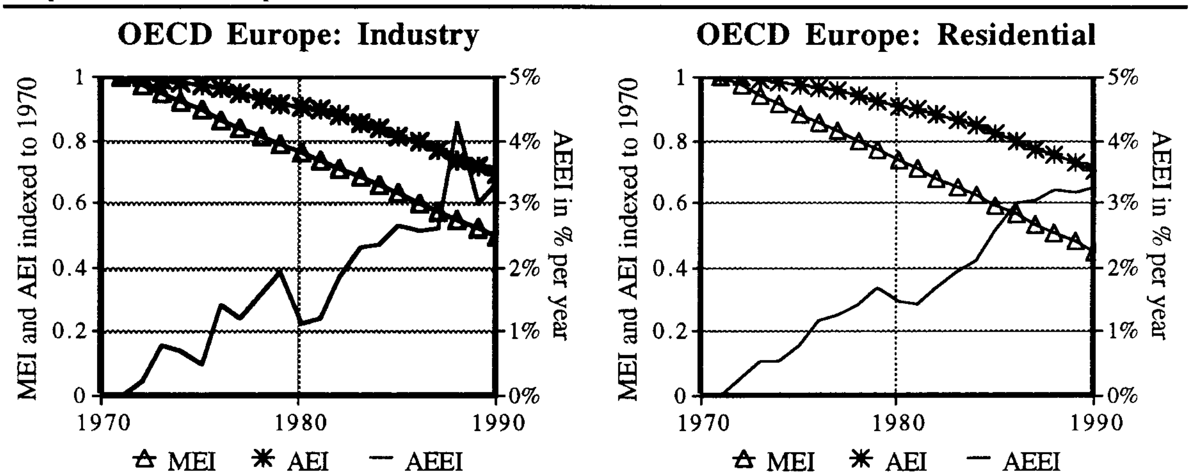
Figure 3.3a shows that as the activity level increased in the 1970-1990 period the energy intensity (heat) decreased in the industrial sector. Figure 3.3b shows that in the residential sector the energy intensity (electricity) increased, however in the 1985-1990 period the energy intensities dropped. The EE model calculations start with calculations on the demand for end-use energy before AEEI and PIEEI; consequently the drawn curves are above the historical data points. Therefore ξ_2 has been set to zero in the industrial sector and ξ_2 has been set greater than zero in the residential sector in the case of electricity (maximum is set at 12000 US$ per year) .

The full set of parameters of Eqn. [1] is presented in appendix C in Tables C1-C5, they are based on these considerations, and derived from the historical data in Figure 3.3 (but also data of the other IMAGE regions) according to the calibration procedure discussed in the introduction of chapter 3.

3.2 Autonomous Energy Efficiency Increase: AEEI

As explained in paragraph 2.2, MEI is assumed to decrease autonomously; an example is given for the Industrial and the Residential Sector in Figures 3.4 for OECD Europe. Both Figures exhibit the same format, on the left y-axis an index for the Average Energy Intensity and the Marginal Energy Intensity is given (indexed to 1970), whereas on the right y-axis the AEEI is presented. On the x-axis the years are shown.

Figure 3.4: Marginal/average energy intensity and AEEI-factor in the Industrial and Residential sector in OECD Europe in the 1970-1990 period.



Note:			
	AEI	=	Average Energy Intensity in GJ per 1990 US $
	AEEI	=	Autonomous Energy Efficiency Improvement in percentages
	MEI	=	Marginal Energy Intensity GJ per 1990 US $

The marginal energy intensity decreases in this case linearly in the industrial and residential sector by about 50 percent resp. 55 percent. Combining the marginal energy intensity function with the growth of the industrial sector results in the average energy intensity and the curve describing the AEEI factor from 1970 onwards. As can be seen the AEEI time-series is disrupted in 1980 since the growth of the industrial sector decreased (which can be seen from Figure 3.2a from 2% per year down to -2% per year) and therefore the amount of newly installed capital decreased in this period. Figure 3.4b indicates that AEEI in the residential sector follows the same trends of the AEEI factor in the industrial sector. In Eastern Europe and the CIS region in the 1970-1990 period no decrease is **assumed** of the MEI.

3.3 Fuel substitution

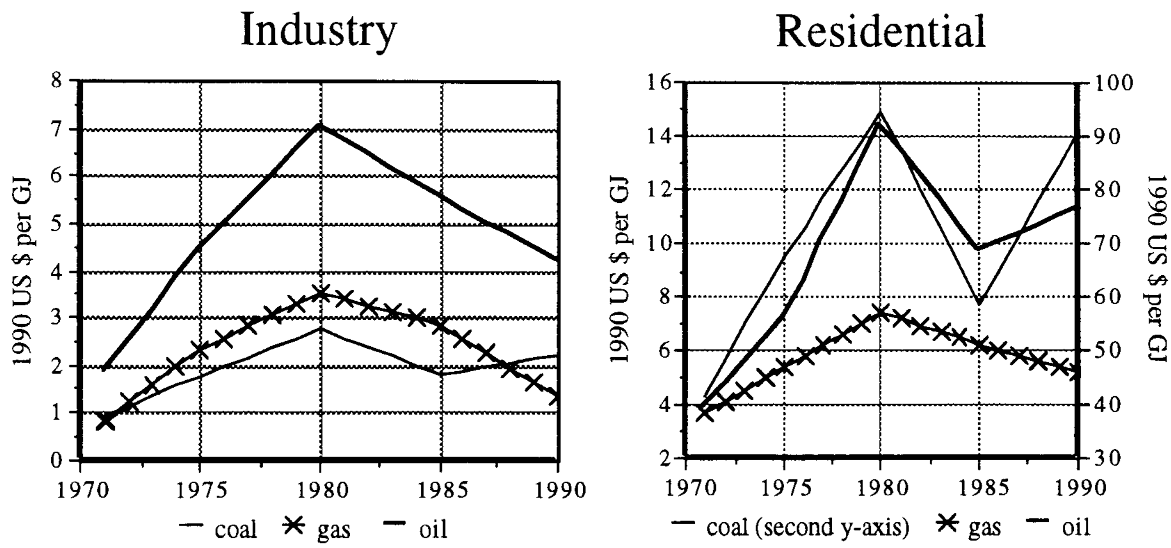
Fuel substitution in reality is driven by the change in relative prices of the different energy carriers. If e.g. the price of coal grows faster than the price of gas, it can be expected that the fuel mix will change over time in favour of gas. A price mechanism has been included in the model as described in Eqn. [8] in section 2.3. It is hard to establish parameter values for the cross price substitution elasticity θ in Eqn. [8] on the basis of empirical data or existing literature. In the current version of the EE model θ is assumed to be sector - (not-region -) specific and assigned a value of 1 to 2 percent. Regional data on sectoral fuel use and prices for the 1970-1990 period are used to calibrate a fixed value for the premium factors given the various cross-price-substitution elasticities.

Two formulations of the general format of the MNL function have been analyzed. First, premium factors have been calibrated to fit the shares of the energy carriers using allocation to work on the whole capital stock, and secondly premium factors calibrated to fit the shares of the energy carriers using allocation **only** on newly installed capacities (as presented in Eqn. [8]). The premium factors derived on historical data are less stable in the second case. Yet, there are indications that fuel-switching is most relevant for newly installed capital equipment. Therefore the second formulation is used in the E-E model. For simulations beyond the year 1990, i.e. scenarios, premium factors are in most cases kept constant at their 1990 value. An exception is made for the premium factor of biofuels in the longer term, as will be shown in section on the reference scenario (Section 4.2).

The price times the premium factor can be regarded as the price in the perception of the agents that make use of a certain energy carrier. It determines on this aggregated level, which market share per energy carrier to work with on the newly installed vintage. Figure 3.5 presents the development of the prices multiplied by a constant premium factor of the energy carriers in the industrial and residential sector in OECD Europe, assuming that in the industrial sector the cross-price-substitution elasticity is equal to 1 percent and in the residential sector equal to 1.5 percent. Be aware that the premium factor for oil has been fixed to one. In 1970 the premium factor lowered the actual price of coal by 40 percent resulting in a perceived price equal to 1.0 1990 US $ per GJ.

Tables D1 and D2 in Appendix D present the input of the MNL function for Eastern Europe and the CIS region.

Figure 3.5: Development of prices ***including*** *the premium factor as input to the Multinomial Logit Function in the industrial and residential sector in OECD Europe.*



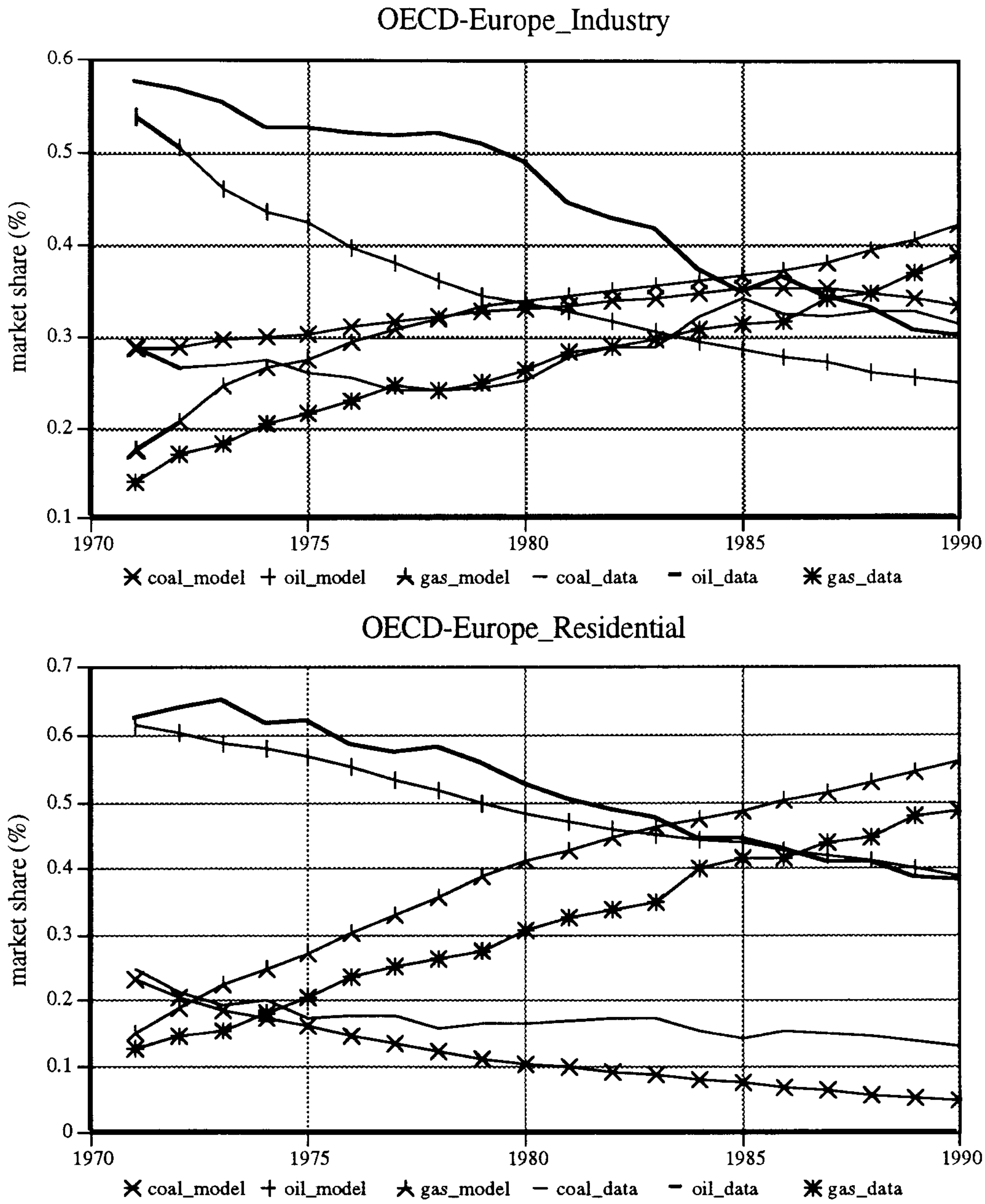
Note: Prices of the energy carriers come from IEA statistics, for oil, premium factors are kept constant at value 1.

In the 1970 the market share for gas in the industrial sector in OECD Europe was equal to 15 percent (Figure 3.6). Figure 3.5 shows that in the 1970-1985 period the perceived price of oil has grown faster and was much higher than the prices of the other fossil energy carriers. After 1985 the perceived price of oil dropped, but compared to the other fossil energy carriers still remained the highest. However after 1990 the perceived price of oil increases again very sharply. Hence the market share of oil should decrease over the 1970-1990 period. This is illustrated by the bold solid line in Figure 3.6. In 1980 in the industrial sector the market shares of the fossil energy carriers are according to the EE model equal to 32 percent, whereas the actual market share of oil was higher (48 percent). The trend, however, that the market share of oil decreased in this sector in the 1970-1990 period is the same (the model predicts over the 1970-1990 period a decrease of the market share of oil in the industrial sector from 55 percent to 25 percent; in reality this was equal to 58 percent to 30 percent).

Figure 3.5 shows, that in the industrial sector in OECD Europe the perceived price of gas in 1970 was almost equal to the perceived price of coal but in 1975 about 25 percent higher. After 1990, however the perceived price of gas again was lower than the perceived price of coal. From Figure 3.6 it can be seen that in 1970 the market share of gas was 50 percent lower than the market share of coal, although the perceived price of gas was almost equal to or higher than the perceived price of coal. This means that the market share of gas had to increase relatively at the cost of the market share of coal. But at the same time the market share of coal had been increasing as well, because the aggregate market share of coal and gas had to increase at the cost of the decreasing market share of oil. This is due to the fact that the market share of oil was relatively high in 1970 compared to the other energy carriers and the perceived price of oil was higher in 1970 and increased faster than the price of the other energy carriers. Around 1987 the market shares of coal and gas in the industrial sector in OECD Europe were the same (25 percent); the EE model generates the same trend but calculates the market shares to be 32 percent. In the 1985-1990 period the perceived price of gas decreased whereas the coal price continued to increase. Hence, the market share of gas increased compared to a decreasing market share of coal, which can also be seen in Figure 3.6 from the developments of the historical market shares of coal and gas in the 1985-1990 period. This development is also confirmed and reproduced by the EE model. After 1985 the gas price increased again. This implies that, according to the EE model growth rate of the market share of gas will decrease.

Since the calibrated premium factor for coal was larger than one, this suggests that the perceived price of coal in the residential sector was much higher than the actual price. The large number for the premium factor of coal may be caused by the existence of externalities due to the use of coal to generate heat in the residential sector. Externalities may be larger in the residential sector than in the industrial sector, using coal on a much larger scale. Industries on the other hand, may be in a better position to eliminate the negative local health effects than the households in the residential sector. Also it can be seen from the lower part of Figure 3.6 that the model is capable of matching all the historical market shares in the case of the residential sector in OECD Europe much better than of the industrial sector.

Figure 3.6: Market shares of the fossil energy carriers in the Industrial and Residential Sector in OECD Europe in the period 1970-1990.

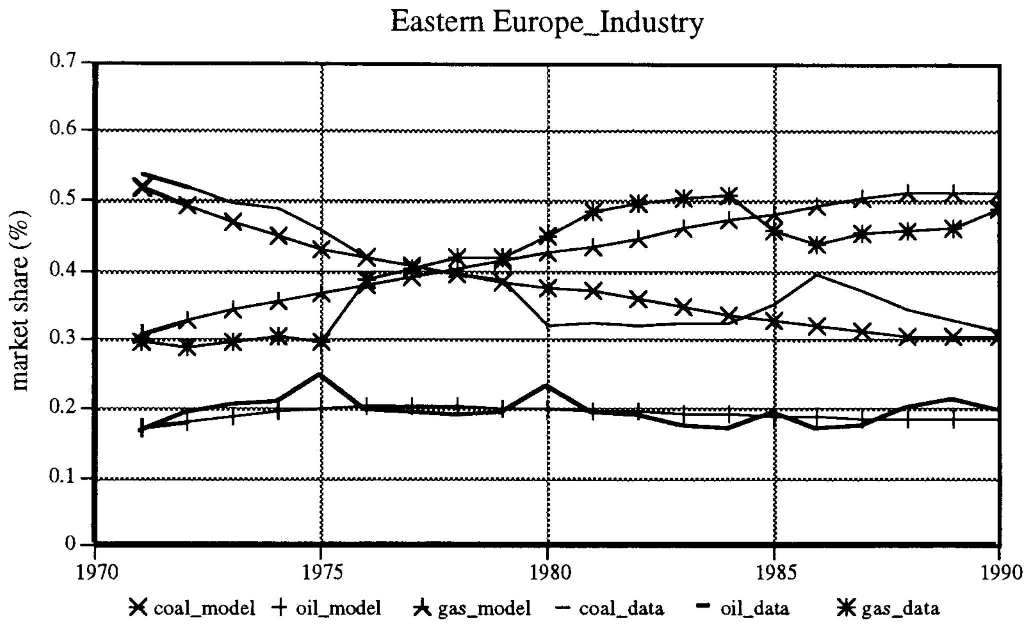


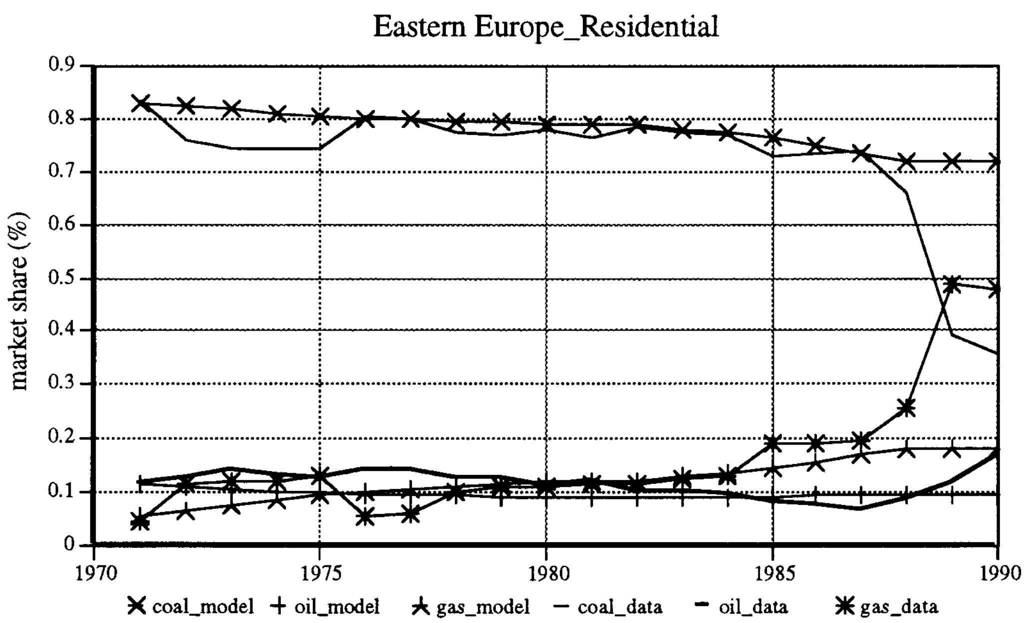
During the 1970-1990 period gas also strongly penetrated very strongly the residential sector in Western Europe. As in the case of the industrial sector, the market share of oil decreased in the 1970-1990 period. This can be attributed to the decreasing perceived price of oil compared to gas (which may be illustrated by taking the ratio of the perceived prices of oil and gas in Figure 3.5). With a small and over time diminishing share of coal, this implies that the market share of gas should follow the opposite trend, which is also confirmed by the lower part of Figure 3.6.

Figure 3.7 presents for the Industrial and Residential sector in Eastern Europe the market shares of the fossil energy carriers over the 1970-1990. As can be seen from Figure 3.7, in Eastern Europe in the industrial sector in 1970 the largest market shares were held by coal, gas and oil (equal to 55, 30 and 15 percent). Ranking the perceived prices by energy carrier results in the following order: oil, coal and gas. This situation remained throughout the 1970-1990 period. Due to the relatively high value of the perceived price of coal (see Table D1 in Appendix D) and the corresponding low long-term value of the market share of coal being equal to 10-15 percent (the historical market share of coal in 1970 was equal to 55 percent), the EE model calculates a declining market share of coal throughout the 1970-1990 period.

The lower part of Figure 3.7 shows that market shares remained constant over the 1970-1986 period. In 1988-1990 the market share of coal dropped from 75 percent down to 35 percent. This huge difference in a rather short period of time can by no means explained by the model. Still, it is known that (as also will be explained in the next section) the demand for heat dropped by 75 percent. This implies that in 1988-1990 a phase out occurred of the capital stock dependent on the use of coal. This could be explained by the relative "age" of the vintage of the capital stock that relies on the use of coal compared to the other vintages generating heat in the residential sector in Eastern Europe, whereas in the EE model only two vintages are used. Another explanation could be that due to the interference of the government the perceived price of coal, as in OECD Europe, had been increased up to levels that lie above the perceived prices of oil and gas. This implies that after 1988 the premium factor of coal and gas has to be increased resp. decreased by a substantial amount. The 50 percent decrease of the market share of coal can, however not be simulated with a two-vintage approach as used in this version of the model.

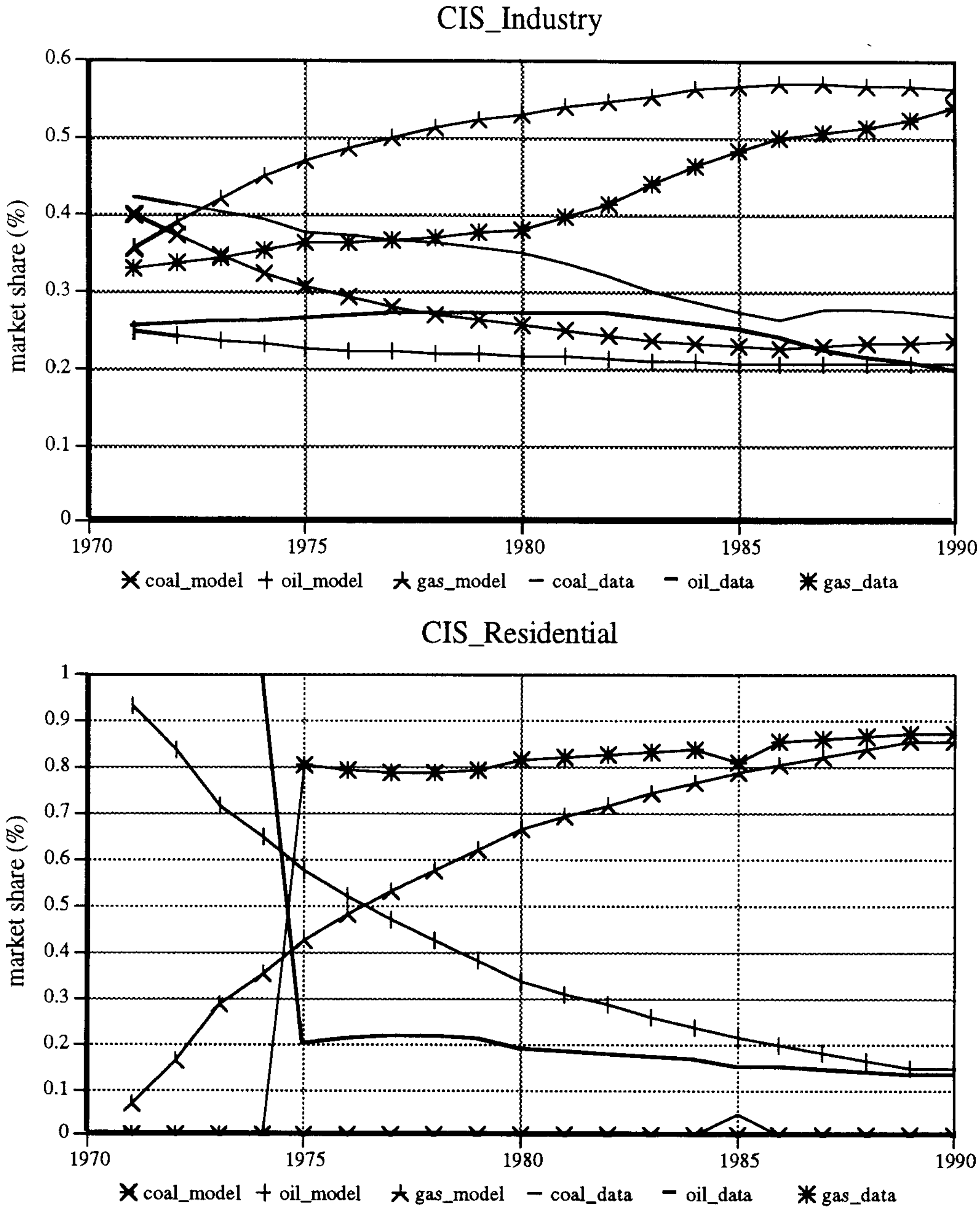
Figure 3.7: Market shares of the fossil energy carriers in the Industrial and Residential Sector in Eastern Europe in the period 1970-1990





Finally the last market share results that will be presented concern the industrial and residential sectors in the CIS region. As can be seen in upper part of Figure 3.8, in 1970 the market shares of gas, coal and oil in the industrial sector were equal to about 30, 45 and 25 percent. The market share of gas increased up to 55 percent, which can also be explained by the EE model.

Figure 3.8: Market shares of the fossil energy carriers in the Industrial and Residential Sector in the CIS region in the period 1970-1990



The lower part of Figure 3.8 presents for the 1970-1990 period, the market shares of the fossil energy carriers in the residential sector in the CIS region . It shows that the market share of coal has always been zero in the past (an exception is seen for the year 1985). Also it can be seen that the market share of oil dropped from almost 100 percent in the early seventies to 20 and 15 percent in 1980 and 1990. Consequently, the market share of oil increased from zero percent in 1970 to 80 and 90 percent in 1980 and 1990. The EE model can by no means explain this huge switch from one energy carrier to another by only one value of the premium factor for the 1970-1990 period. The market shares of oil and gas that the model calculates for the year 1990 do not differ significantly from historical data.

3.4 Cost curves

In this Section we discuss the investment cost curves per sector per energy function and the relationship between the rise of costs of end-use energy over time and the reduction of the energy intensity.

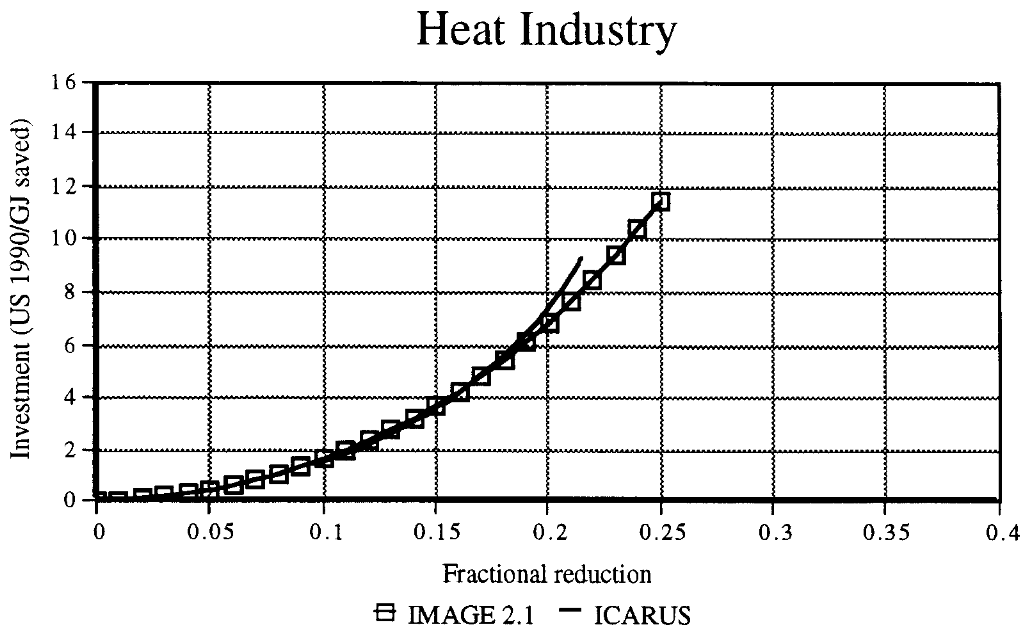
Appendix B explains the method for transforming the energy conservation investment cost curves per region, sector and energy function to regional CO_2 investment cost curves. It also explains in detail how the investment curves should be transformed, if for each year 1970+t only presentation is wanted for the energy conservation measures in addition to the measures already taken in the period [1970,1970+t]. The resulting investment cost curve per sector per region per energy function can be fitted against investment cost curves that can be found in the literature. In this report this has only be done for all sectors and energy functions of OECD Europe.

The investment cost curves have been tested against the investment cost curves that are derived from the ICARUS database. The database includes data of the year 1990 on the costs and effectiveness of implementing measures focussing on the reduction of CO_2 emissions by end-use energy conservation in the Netherlands. A detailed description of the database can be found in Blok *et. al.* (1990).

In all the other cases **first** order estimates of the parameters of the investment cost functions were set equal to the OECD European case. These parameters were used to calculate the demand for end-use energy per sector for each region. The results were checked against historical values. If marginal changes of the parameters of the investment cost curves could lead to significantly better results, then the parameters of the investment cost curves have been adjusted.

In Figure 3.14 the bold line is the representation of the cumulative investment cost curve of the energy function heat in the industrial sector in the Netherlands.The other line is the result of model calculations as described in the first two steps of the procedure as presented in Appendix B. Figure 3.14 shows that the assumptions of the model lead to potential investment costs in 1990 of energy conservation measures that agree with results from the ICARUS database.

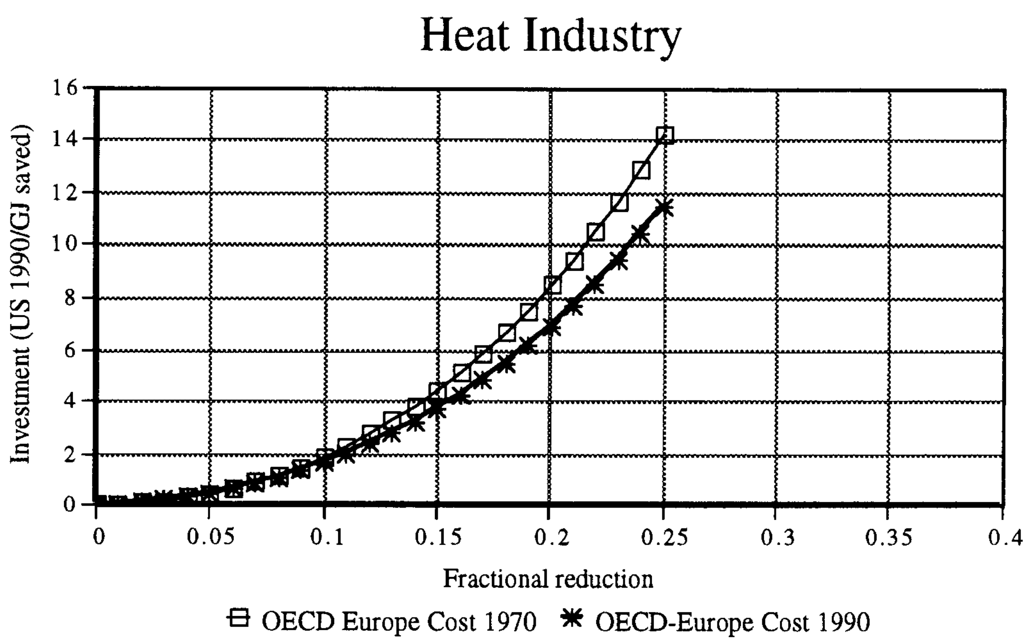
Figure 3.14: ICARUS cost curve of the final demand for heat in 1990 in the Industry in the Netherlands

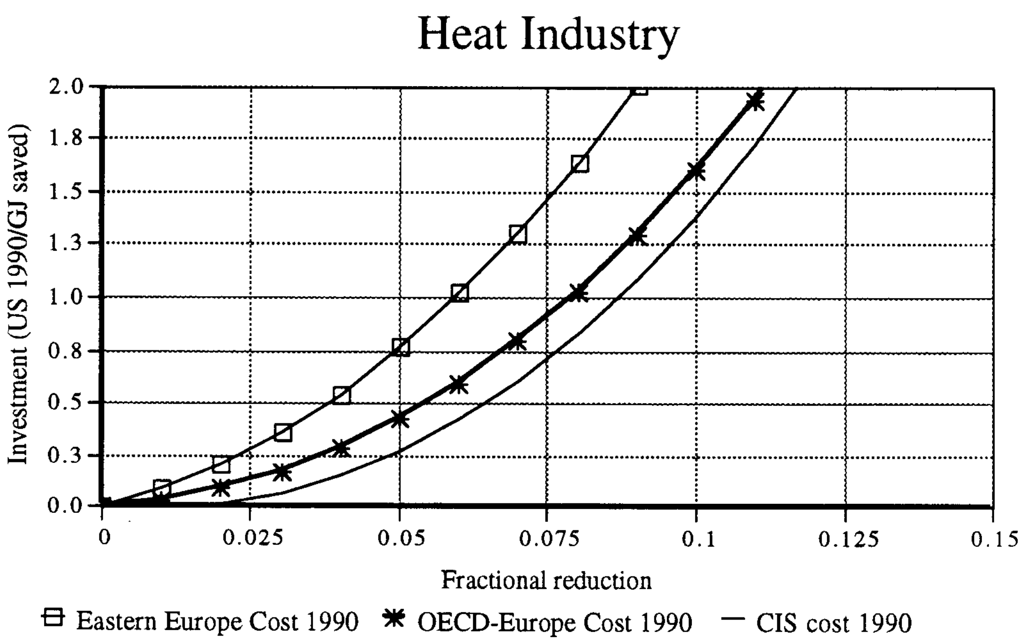


In the upper part of Figure 3.15 the dynamical aspects of the cumulative investment cost curves as implemented in the EE model is presented. The upper curve refers to the investment cost curve prevailing in 1970; the lower refers to 1990. Two effects occur on the level of investment costs when taking additional investments. First, as time evolves the level of costs declines autonomously of those measures that have not yet been taken. Secondly as the cost price of generating end-use energy increases this implies that the marginal and cumulative costs of additional (or the potential) investments in end-use energy conservation increases. This is already explained in more detail in the section 2.4. Figure 3.15 shows that the first effect of the autonomously declining costs outweighs the second. This means that investment cost curve in the industrial sector in OECD Europe in 1990 compared to 1970 is lower. However, this would not have occurred if, e.g. in the past the cost of end-use energy had risen more sharply than it actually did. In the latter case, more end-use energy conservation would have taken place in the past and in 1990 the demand for end-use energy could only be reduced by taking into account the more expensive energy conservation measures. The top of Figure 3.15 illustrates that a 25 percent reduction of the energy intensity in the Industrial sector in 1970 compared to 1990 the cumulative investment costs has fallen by about 20 percent .

Investment cost curves of Eastern Europe and CIS in 1970 were assumed to be 15 percent lower than the OECD European case. This leads to acceptable energy conservation patterns over time. It has to be recognized that improvements on investment curves still can be made, but this will be the subject of research that will be conducted on the EE model in the course of 1995. The lower part of Figure 3.15 shows that for a 5 percent reduction of the 1990 energy intensity in the Industrial sector the investments costs per GJ in Eastern Europe and the CIS region are 40 percent higher and 33 percent lower than compared to the situation in 1990 in OECD Europe.

Figure 3.15: In the upper part investment cost curves are presented for the industrial sector in 1970 and 1990 in OECD Europe; in the lower part three cost curves are presented for the industrial sector in 1990 in OECD Europe, Eastern Europe and the CIS region



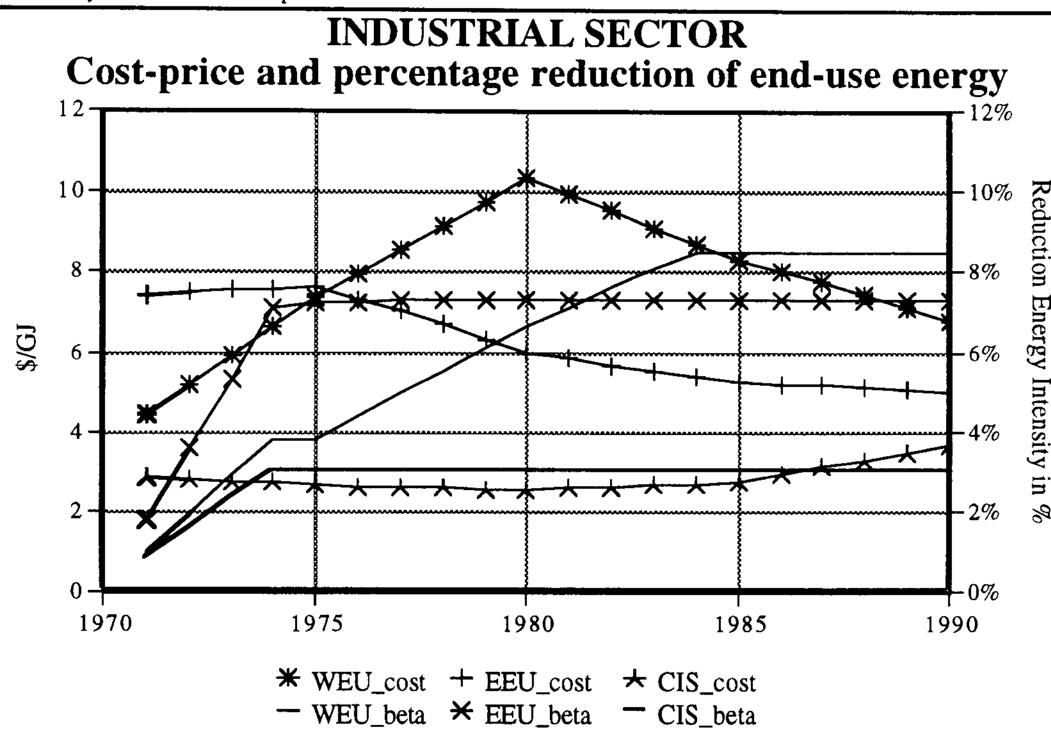


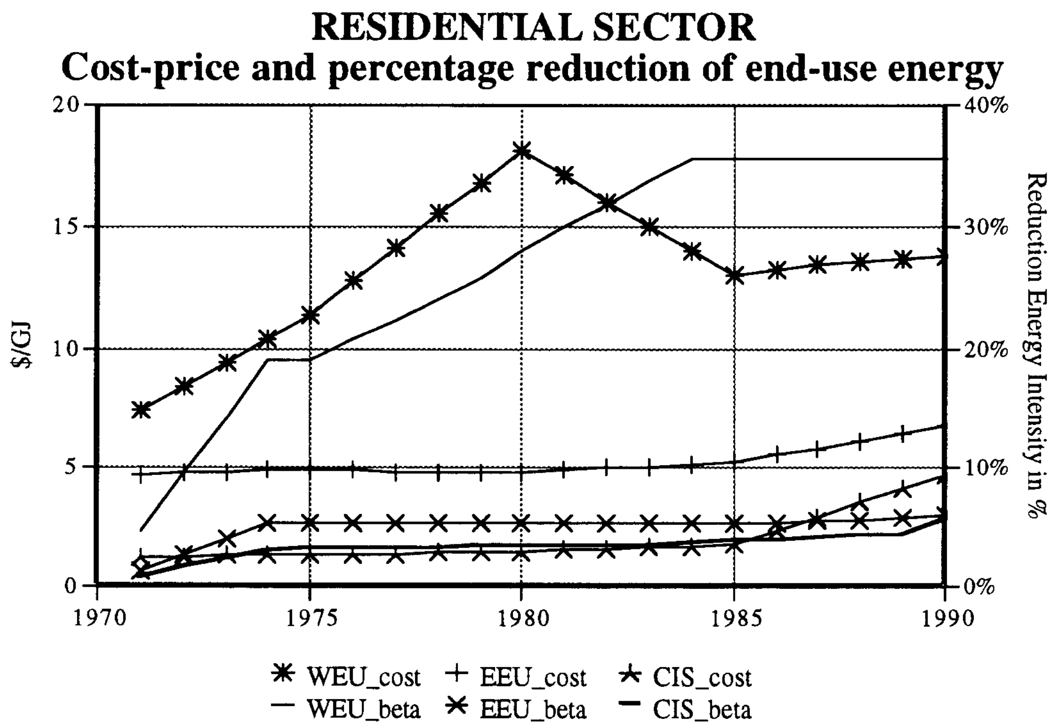
The last part of this section deals with the reduction of the energy intensity as a function of the increase of the costs of useful energy. In Figure 3.16 for OECD Europe, Eastern Europe and the CIS region in the residential and industrial sector, the reduction of the energy intensity and the average cost price of end-use energy heat is plotted against time for the 1970-1990 period. The upper part of Figure 3.16 presents the model results for the industrial sector. According to the EE model, in OECD Europe the cost of heat increased in the 1970-1980 period from 4 to 10 1990 US $ per GJ (as can be seen from the WEU-cost line), in the same period the price induced additional reduction of the energy intensity increased up to 7 percent (as illustrated by the WEU-beta line). Although the cost price decreased after 1980, the reduction of the energy intensity at the same time had been increasing as well. This can be attributed to the assumed delayed response of agents to price increases of heat. Between 1985 and 1990, according to model calculations, no additional PIEEI occurred.

Also it can be seen from Figure 3.16 that in the 1970-1990 the industrial sector in the CIS region the cost price of heat has been much lower than in OECD Europe and has been constant from 1975 onwards. Moreover, since no autonomous decline of the cost functions are assumed for Eastern Europe and the CIS region, an increase of the reduction of the energy intensity has not occurred during the 1975-1990 period.

The lower part of Figure 3.16 presents the results for the Residential sector in OECD Europe, Eastern Europe and the CIS region. This Figure exhibits the same format as the top Figure. Apart from the numbers on both y-axisses, the shape of the function is equal to the lines drawn for the industrial sector.

Figure 3.16: Cost prices and reductions of the energy intensity in the industrial and residential sector for the energy function heat for the 1970-1990 period.





Note: Autonomous decline investment cost functions: In OECD Europe in the industrial sector equal to 0.5% per year in the 1970-1980 period and 3% per year in the 1980-1990 period. In Eastern Europe and the CIS region no autonomous decline of the investment cost function is assumed for the 1970-1990 period.

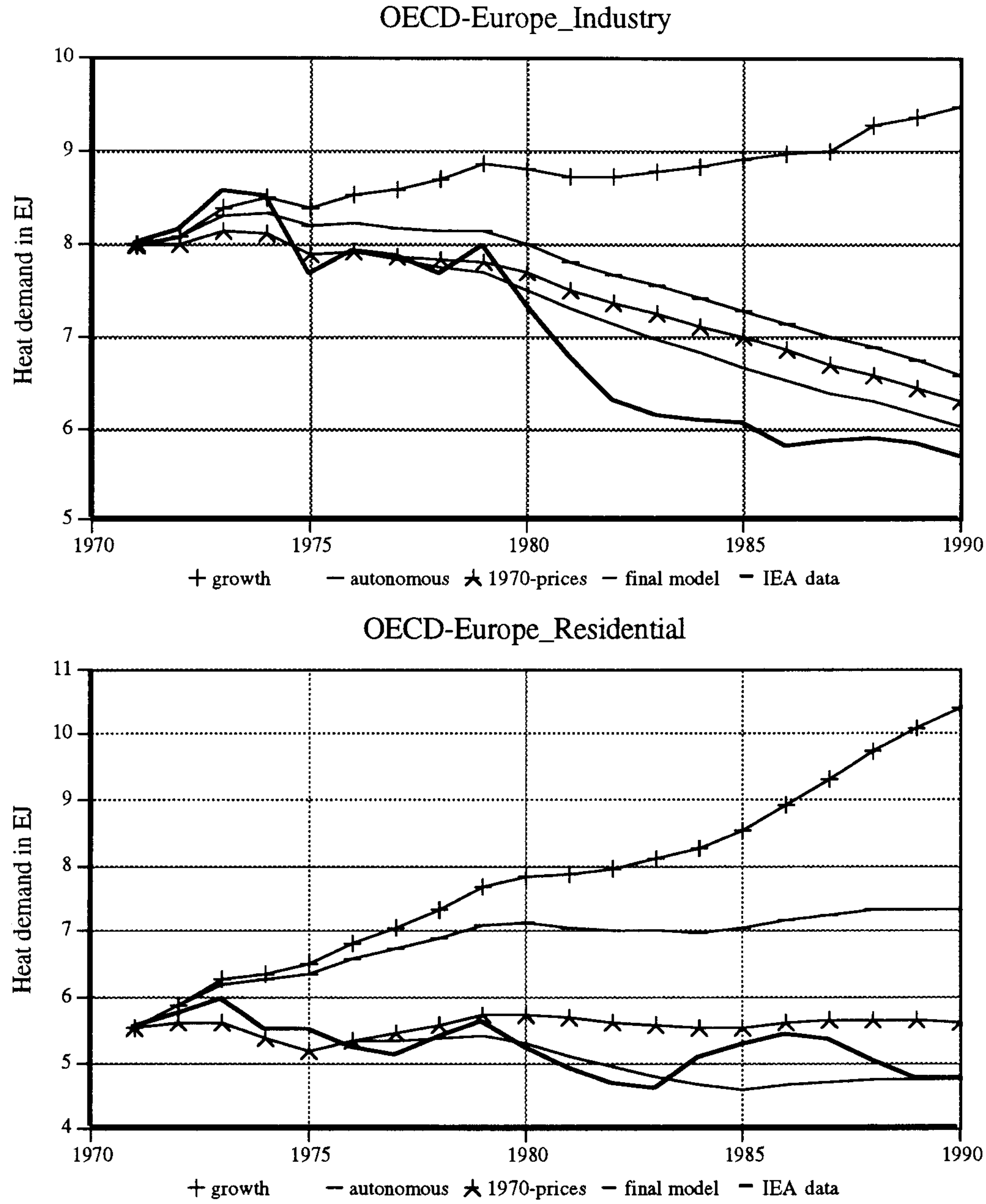
3.5 Heat demand in the Industrial Sector in three regions

In the preceding section various elements of the calibration process and the EE model have been presented. Given the end-use and the AEEI factor estimates, a demand for secondary fuels is calculated. Depending on apparent fuel paths and on energy conservation cost curves, the actual demand for the secondary fuels is calculated. Only three regions and two sectors are presented in this section; the industrial and residential sector in OECD-Europe, Eastern Europe and the CIS region. Most of the other regions are treated in the same way as presented for these three regions and two sectors, but will not be presented in this report.

Figures 3.16, 3.17 and 3.18 show the outcome for three regions. The "growth line" in each figure refers to the end-use energy before AEEI and PIEEI, from Eqn. [1] in Section 2.1. The "autonomous line" adjusts the first line by the AEEI factor. The third line "1970 prices line" is equal to the second line, but adjusted for PIEEI effects, given the price levels of the secondary energy carriers that existed in 1970. An increasing discrepancy with the autonomous line is due to increased energy conservation (as presented in Section 3.4). This reduction of the energy intensity is the consequence of an autonomous decline of the investment cost functions, given the 1970 price levels of the secondary energy carriers. The next line (beta-line referring to β defined in Section 2.4) corrects the 1970-line by PIEEI effects due to changing levels of the prices of secondary energy carriers. This is the final model calculation and should be comparable to the bold line in the figures, the historical data coming from IEA statistics.

The top of Figure 3.17 presents the case of the energy function heat in the industrial sector in OECD Europe for the 1970-1990 period. Starting in 1970 the total heat demand equalled 8 EJ. A moderate increase of the heat demand occurred in the years 1971, 1972, 1973, followed by a decline down to the level of heat demand of 1970. From 1980 onwards the demand for heat decreased down to 6.1 EJ, followed by a moderate decline down to 5.8 EJ up to the year 1990. The EE model underestimates heat demand in the 1971-1975 period, gives a perfect match in the 1975-1980 period.The EE cannot catch up with the rapid decline in the 1980-1985 period, but it does produce a declining trend that levels off after 1985 as is the case with historical developments. The declining demand according to the EE in the 1975-1980 period is the consequence of the declining growth of activity levels which can be seen from Figure 3.2, but also comes from the fact that the EE model calculates for this period the maximum value of AEEI (see Figure 3.4) and the increasing PIEEI of 1 procent per year (the difference between the autonomous line and the beta line). A better fit could probably be achieved when the industrial sector would be disaggregated and better proxy variables could be used for the activity level of industrial sub-sectors.

Figure 3.17: Heat demand in the industrial and the residential sector in OECD Europe in the 1970-1990 period.



The lower part of Figure 3.17 presents the results of the EE model for Eastern Europe and the historical developments. It can be seen that the demand in 1970 was about 5 EJ and it remained so for the 1970-1990 period. The EE model computes that the demand for AEEI and PIEEI would have grown by 100 percent. According to the EE model, savings in the heat demand in the residential sector can mainly be ascribed to effects in AEEI, followed by effects of the autonomous decline of the investment cost function and only a marginal effect due to price increases. The EE model calculates that PIEEI was the strongest in the early eighties.

The results for the heat demand in the 1970-1990 period in Eastern Europe are presented in Figure 3.18; the industrial sector in the upper part and the residential sector in the lower part of the figure. As can be seen from Figure 3.18, the AEEI factor is assumed to have been equal to zero in the past. Figure 3.18 also shows that in Eastern Europe no PIEEI occurred due to price increases of the different energy carriers compared to the 1970 price levels.

The fall of the heat demand by 25 percent in the period 1988-1990 cannot be explained by the EE model, since the decrease of the Value Added in the industrial sector results in a computed energy intensity (before corrections on PIEEI and AEEI) greater than in 1988. This is the consequence of the application of Eqn. [1] with ξ_2 equal to zero as can be found in Table C1 in Appendix C. The results of the EE model could be improved by assuming that the energy intensity (before being corrected for AEEI and PIEEI) remains constant in the cases that a decline in the activity level occurs. This assumption implicitly states that restructuring of an economic sector is irreversible. Also it should be noted that according to the model, given the assumptions made for Eastern Europe, the PIEEI has remained constant since 1975.

In the lower part of Figure 3.18 the EE model results are presented for the residential sector. Most of the characteristics of the developments of the demand for heat in the industrial also hold for the residential sector.

Figure 3.18: Heat demand in the industrial and the residential sector in Eastern Europe in the 1970-1990 period.

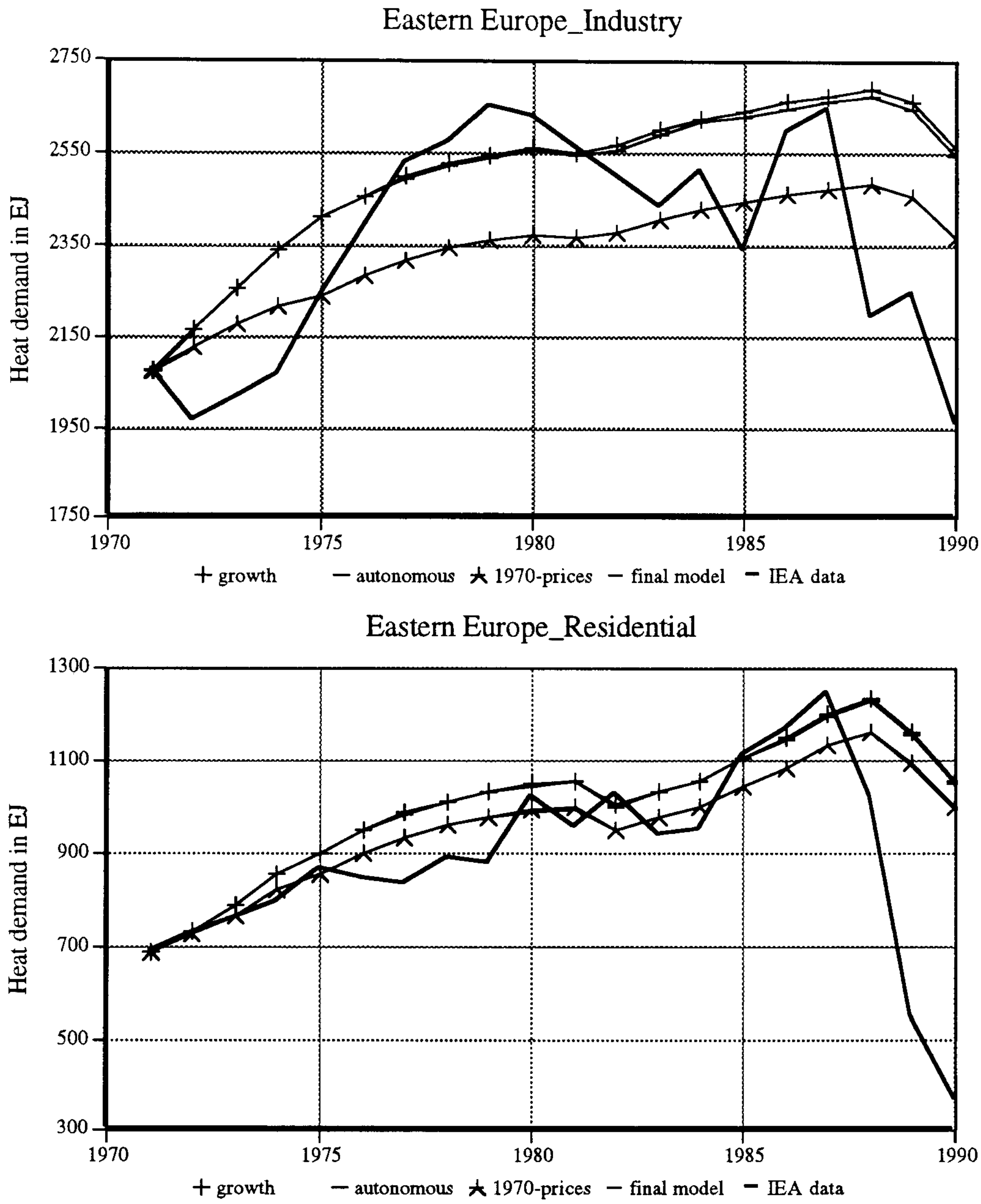
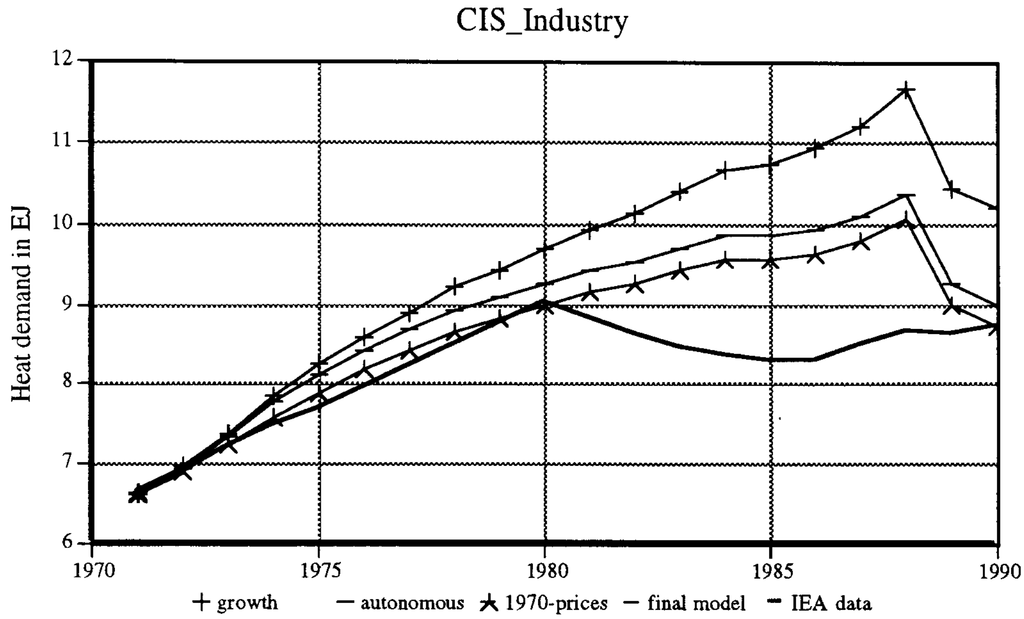
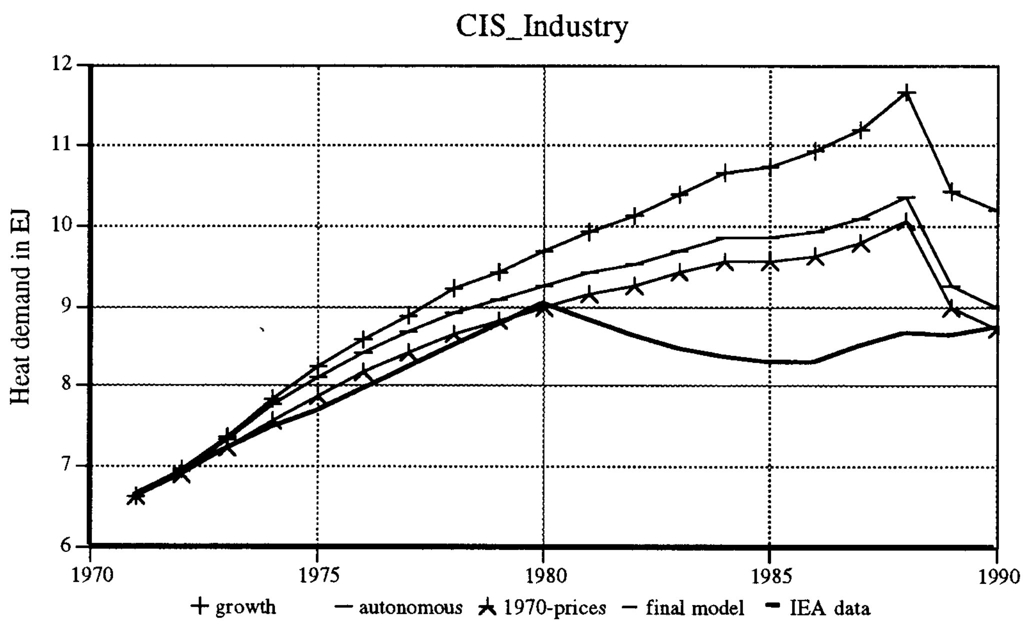


Figure 3.19 presents the results of the EE model for the CIS region over the 1970-1990 period. As can be seen from the upper part of the Figure 3.19, the increase of the demand for heat in the industrial sector rises from 6.5 EJ in 1970 to 9 EJ in 1980, which is fairly matched by the EE model. The 1975-1985 period rise of the cost of useful energy nor the effects of AEEI can explain the sudden stabilization of the demand for useful energy in the 1980-1985 period. However, the EE model, with its current parameter set can match the historical demand for heat in the industrial sector of 1990.

Figure 3.19: Heat demand in the industrial and the residential sector in the CIS region in the 1970-1990 period.





The lower part of Figure 3.19 indicates that neither AEEI nor PIEEI significantly influenced residential energy consumption.

The last remark made in this section, is that the other sectors were treated in the same way as was done for the presented sectors/regions and energy functions. The overall result is that the model performs well for those sectors that contribute significantly to total energy demand. For the other sectors additional analysis will be performed.

4. Applications

Three applications of the IMAGE 2.1 model will be described in this section. The first two deal explicitly with investment cost functions. The time horizon for these applications are the period 1990-2010. In section 4.1 regional investment cost curves will be presented for the years 1990, 2000 and 2010. In section 4.2 the CO_2 investment cost curves are used to define and make a preliminary assessment of the potential of the instrument Joint-Implementation. Finally in Section 4.3 a short presentation will be given of the results of the demand for energy in the 1990-2100 period.

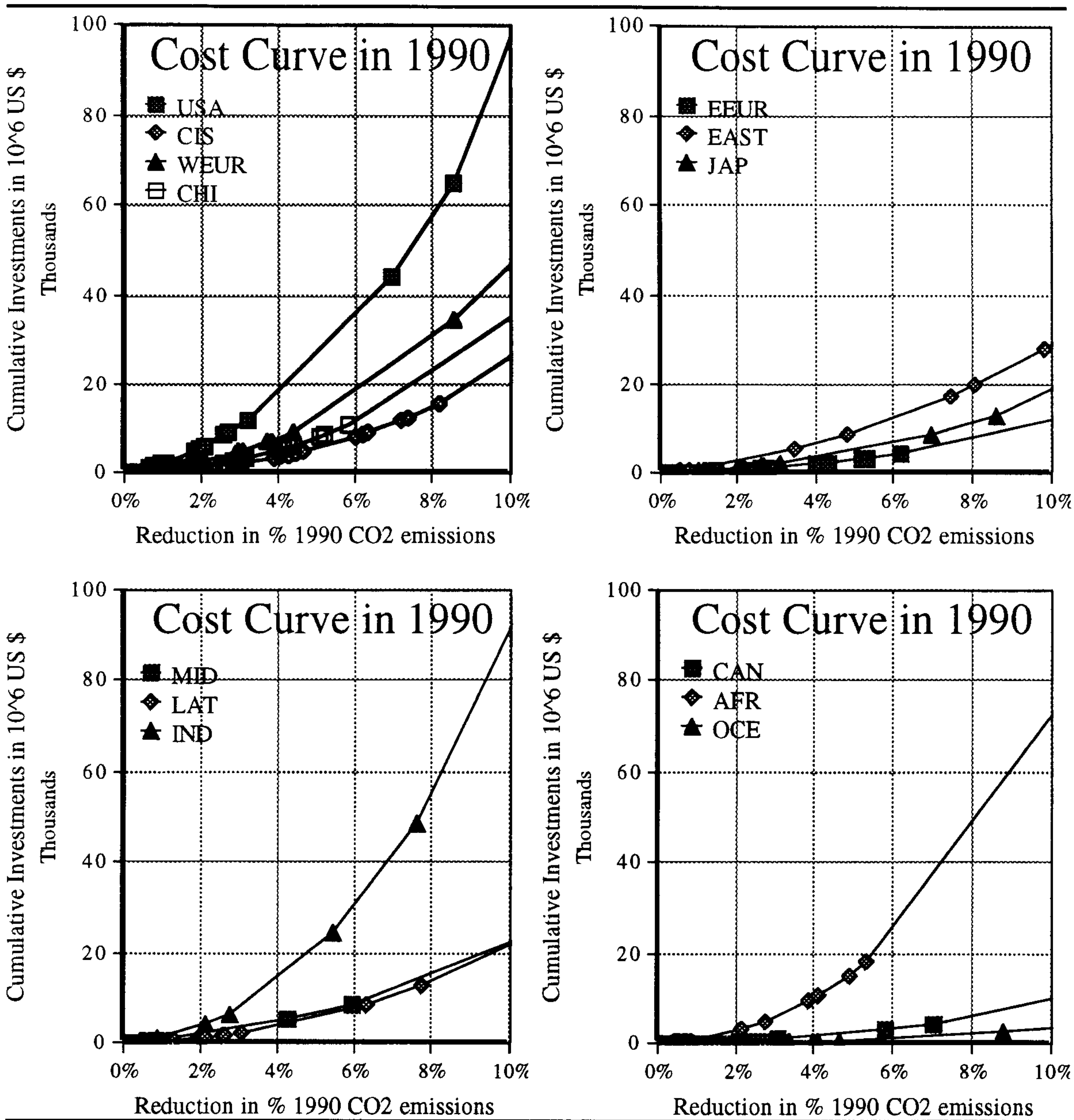
The main scenario assumptions that are used for these applications are described in Appendices D and E, and follow in general the IS92a scenario of the IPCC (Legget *et. al.*, 1992).

4.1 CO_2 investment cost functions for the years 1990, 2000 and 2010

The EE model makes it possible to calculate additional investments in energy conservation and reductions on the CO_2 emission levels for target years in the future. It should again be mentioned (see Chapter 2) that not all energy conservation measures are included to reduce the CO_2 emission level, because the supply side is not included in this analysis as well as second order effects on the activity levels if a carbon tax is imposed on energy demand.

The **regional CO_2 cost curve** not only depends on the level of investment costs per GJ saved per sector but is **mainly** determined by the total demand for end-use energy within each sector in that region and the secondary energy carriers that are used to fulfil this demand. These data have been taken into account. Although it can be argued that the marginal costs of energy conservation per sector for each region should have been used, it is believed that in the present approach this only leads to a small error in the calculations. Below in Figure 4.1 the regional CO_2 reduction cost curves for the year 1990 are presented for each region as currently implemented in the IMAGE Energy-Economy model.

Figure 4.1 CO_2 reduction cost curves, aggregated over economic sectors



The curves show the cumulative investment requirement for the reduction of a particular *percentage* of CO_2 emissions. Obviously, the absolute reduction of CO_2 emissions depends on the amount of total emissions of each region. Furthermore, the characteristics of the investments (lifetime, technological requirements) may differ between regions. Nevertheless, the curves show considerable differences in investment costs between regions. Additionally, a non-linear shape can be observed, indicating increasing marginal investment costs.

Figure 4.2 and 4.3 present the required investment costs for energy conservation in 2000 and 2010 respectively, with regard to the scenario assumptions mentioned in Appendices D and E.

Also it should be mentioned that regional estimates of the CO_2 are reported in the next section, which presents a preliminary assessment of the potential of Joint-Implementation.

In most regions, cost curves shift downward with time because of an autonomous decline of investment costs of end-use energy conservation measures for each sector and energy function. The strongest decrease in investment costs is to be observed in Asian developing countries and Africa.

Figure 4.2: End-use energy conservation curves, aggregated over economic sectors in 2000

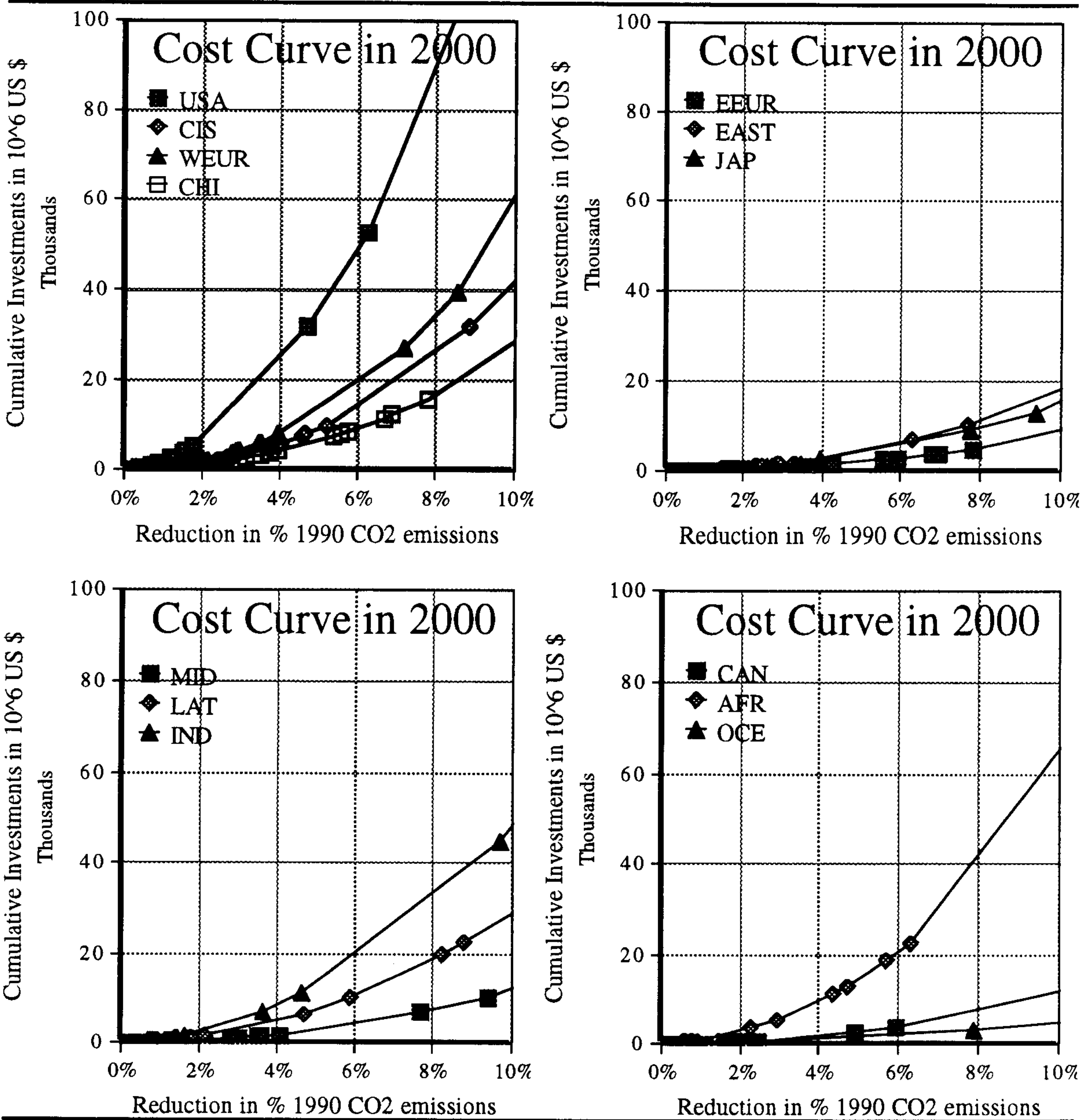
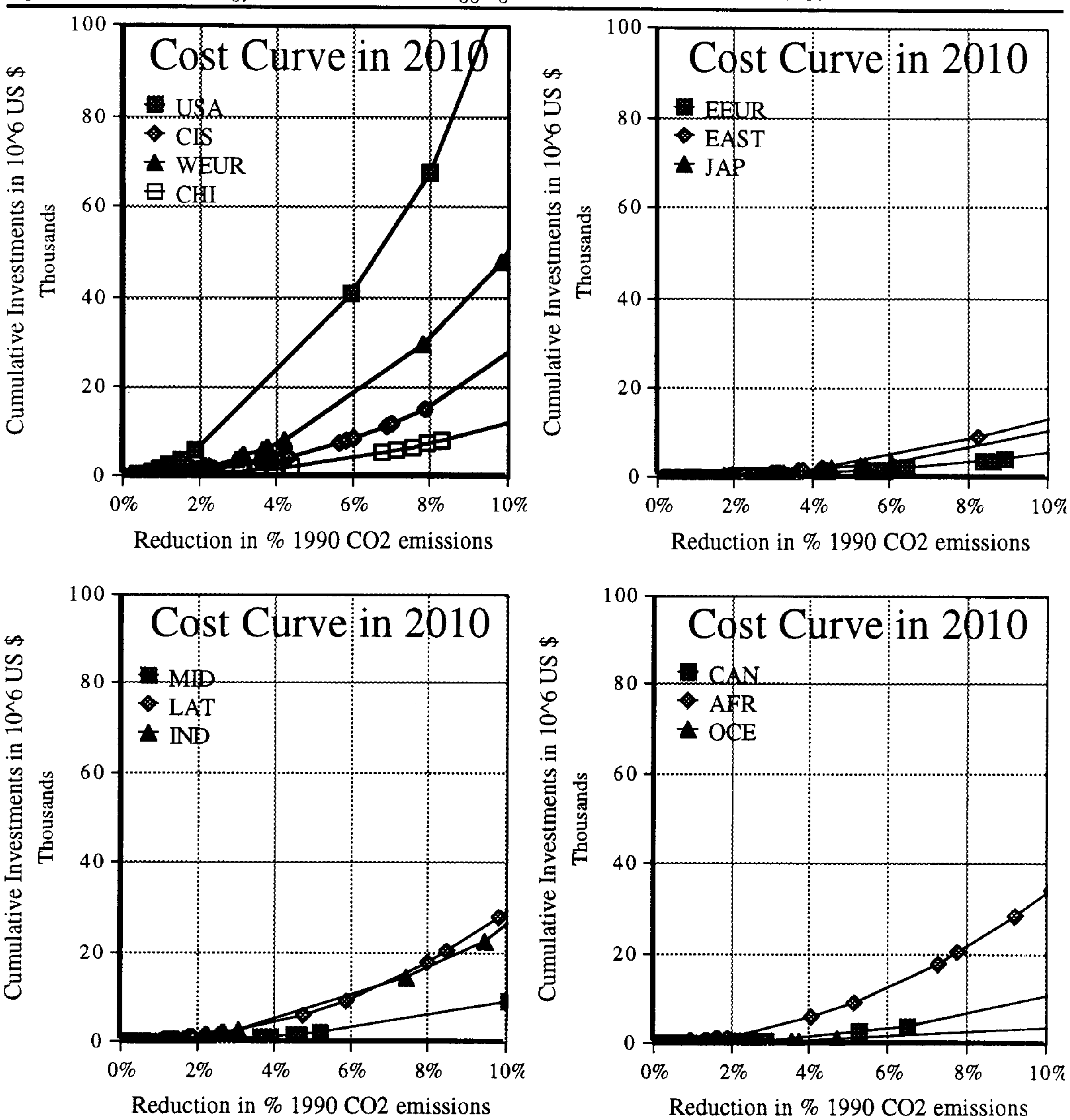


Figure 4.3: End-use energy conservation curves, aggregated over economic sectors in 2010

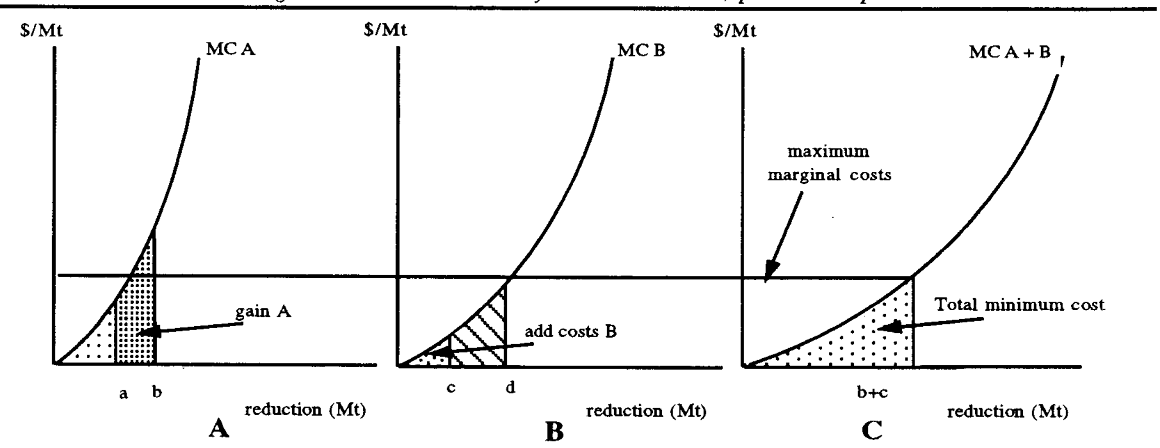


4.2 A first assessment of the global potential of Joint Implementation[1]

Joint Implementation (JI) is a means for reaching cheaper solutions to CO_2-emission reductions. The global potential for JI is defined as the portion of the necessary regional CO_2-emission reductions to meet the goals defined for a target year that can be more cheaply implemented in other regions. The goals will come from multilateral negotiations and may be the starting point of any bilateral negotiation process concerning JI-agreements.

To illustrate some aspects on JI, some explanation will be given below for two regions. If for these two regions CO_2 emission pathways are confronted with targets, the necessary emission reductions can be calculated. Combining net marginal investment cost curves of two regions will demonstrate which options should be implemented to maximize cost effectiveness. In Figure 4.4 the aggregate marginal cost curves of two regions -say A and B- are given. The countries have agreed to save *b* and *c* Mt CO_2, respectively. Region A's 'cheap' options to abate emissions are relatively limited compared to region B's. If both regions would separately meet their obligations, total costs would amount to the sum of the areas below the marginal cost curves limited by *b* and *c*, respectively. If these two regions would co-operate in their search for the most cost-effective way to abate (b+c) Mt CO_2, total cost would be minimal (the shaded area in figure C). In the situation with co-operation, region A would reduce emissions by *a* Mt only and region B would reduce *cd* Mt more than in the 'separate' solution. The additional costs of region B (which reduces more) are outweighed by the gains of region A (which reduces less). region A could finance the additional costs of measures in country B, for example through Joint Implementation, and still be better off.

Figure 4.4: Separate marginal cost curves of two region A and B; aggregate marginal cost curve of the region A and B. On the x-axis the reduction is given in Mt C and on the y-axis the costs in $ per Mt C is presented.



[1] The results presented in this section are more extensively reported in Bollen *et. al.* (RIVM report, 1995).

An aggregate marginal reduction cost curve for the world as a whole can be constructed. Aggregating the national emission reduction targets, it is possible to calculate the size of a theoretical 'fund' appropriate for abating the total volume of emissions (the area under the collective marginal cost curve). Under the requirement that this 'fund' is to be reallocated in the most cost-efficient manner by an omniscient decision-maker, the set of the most cost-effective reduction projects can be established. Furthermore, financial obligations and transfers among countries can be determined.

The purpose of this practise is to determine the *borderline* minimum costs of an emission reduction strategy in which parties establish perfect cooperation. The other extreme, the maximum costs of emission reduction, is defined by a strategy in which parties operate completely independent from one another. The difference between the *soloistic* strategy and the *joint* strategy can be considered either the allocation efficiency loss or the joint implementation efficiency gain (dependent on the angle of incidence).

The potential for JI is therefore defined in this paper as the percentage of necessary regional CO_2 reductions for a target year that can be more cost-effectively implemented in other regions. For example, if it is necessary to reduce emissions in a region by 200 Tg C/yr in order to reach a particular target for that year and it would be cheaper for that region to pay another region to reduce 150 Tg C / yr, then the potential of JI is in this case equal to 150 / 200 = 75 percent.

To assess the potential of JI in the period 1990-2010, it is necessary to know the CO_2 reduction targets of the various regions. The Convention on Climate Change has established targets for OECD countries and Central and Eastern European countries *for the year 2000.* There are no globally agreed-upon targets for the period 2000-2010, nor are as yet there reduction targets for developing countries. Hence, some assumptions have to be made. Three groups of regions are distinguished: developed (OECD) countries, Central and Eastern European countries, and developing countries.

It is assumed that developed countries commit themselves to a stabilization of CO_2 emissions by the year 2000 and a 10 per cent reduction of CO_2 emissions in 2010 (without claiming clairvoyance on the outcome of the political negotiations or suggesting that this reduction will be adequate in any way). Economies in transition will commit themselves to stabilizing emissions of CO_2 in the period 1990-2010 to 1990 emission levels. No targets are assumed for the developing countries and regions.

Table 4.1 presents the main results of the scenario calculations. The first two columns indicate the relative change of CO_2 emissions per region from 1990 to 2000 and 2010, respectively. Indexing the CO_2 emissions in 1990 at 100, Canada will emit 94 in 2000 and 92 in 2010; Japan will emit 115 in 2000 and 128 in 2010; etcetera. The last row shows that world emissions will rise to 112 in 2000 and 145 in 2010. In other words, without CO_2 reduction measures, the world emissions in 2010 will be 45 percent higher than in 1990.

Table 4.1: CO_2 emissions in the year 2000 and 2010 (indexed to regional 1990 CO_2 emission levels); Base case targets (reductions compared to the regional 1990 CO_2 emission level) in 2000 and 2010; CO_2 emissions in the second and third column; necessary to meet the defined targets in the fourth and fifth column (in percentages of 1990 CO_2 emission levels); The optimal allocation of the regional reductions in 2000 and 2010 to meet the global CO_2 emission reduction mentioned in the sixth and seventh column (in percentage of the regional 1990 CO_2 emission level).

Regions	CO_2 index 1990		goals in 1990 %		CO_2 reductions to meet targets		Optimal Allocation	
	2000	2010	2000	2010	2000	2010	2000	2010
Canada	94	92	0	10	-6.4	2	0.7	3.4
Japan	115	128	0	10	15.2	38	1.3	7.1
Oceania	129	146	0	10	29.1	56	0.6	6.3
USA	102	100	0	10	2.0	10	0.6	2.7
OECD Europe	100	102	0	10	0.4	12	1.5	4.9
CIS	65	100	(0)	0	-	0.4	2.1	9.2
Eastern Europe	97	126	(0)	0	-	26	3.0	13.8
Africa	123	177	-	-	-	-	0.2	2.3
China+C.P.Asia	157	266	-	-	-	-	2.8	18.4
East Asia	162	203			-	-	1.7	7.2
India Region	150	236	-	-	-	-	0.6	3.8
Latin America	101	103	-	-	-	-	0.7	3.0
Middle East	112	136	-	-	-	-	1.5	6.2
OECD	103	104	0	10	3.4	14	1.0	4.0
CEIT	73	107	(0)	0	0	7	2.3	10.3
LDC	141	211	-	-	-	-	1.6	9.6
World	112	145	-	-	1.5	7.4	1.5	7.4

Columns three and four present the assumed reduction targets or goals per region for 2000 and 2010 respectively, in terms of a percentage of 1990 emissions. OECD countries have agreed to stabilize their emissions in 2000 at 1990 levels, so their reduction target for 2000 is 0. For 2010 we have assumed a reduction of 10 percent of 1990 levels. LDCs have no targets in the Base Case.

The difference between the projected emissions and reduction targets gives the amount of CO_2 reductions needed to meet the targets. Columns four and five present the percentage CO_2 reductions to meet the targets in 2000 and 2010, respectively. This can be illustrated for OECD Europe, for example. In 2000, the emission index is 100.4. In order to stabilize emissions at the 1990 level (is 100), emission reduction should be 100.4 - 100 = 0.4 per cent. In order to decrease emission in 2010 with 10 percent, emission reduction should be 102-90 = 12 percent. In order to meet the assumed targets, world emission reduction should be 1.5 percent in 2000 and 7.4 percent in 2010.

The last two columns show how these world emission reductions are distributed over the different regions in a least-cost solution (based on the investment cost functions and the methods explained in Appendix B). The potential of JI can be calculated as follows. In 2000, Japan, Oceania and USA reduce less in the optimal solution. In the separate solution they would have to reduce 15.2%, 29.1%, and 2.0% of their 1990 emissions, respectively. In the optimal solution they only have to reduce 1.3%, 0.6%, and 0.6%, respectively. Hence, the potential for JI is:

Japan	(0.152 - 0.013)	x	282 Tg	= 39 Tg
Oceania	(0.291 - 0.006)	x	79 Tg	= 22 Tg
USA	(0.02 - 0.006)	x	1424 Tg	= 20 Tg
Total				= 81 Tg

Expressed as a percentage of world emission reduction in 2000 (0.015 x 6712 Tg), the potential of JI amounts to 80 percent.

The potential of JI is calculated to be 80 percent in 2000 and 65 percent in the year 2010. In other words, for the years 2000 and 2010, respectively 80 percent and 65 percent of the necessary emission reductions to meet the targets for each region could be more cheaply accomplished abroad.

Another important result is that OECD Europe, in the year 2000, is not a potential *donor* of JI projects, but a potential *host*.. In the optimal case OECD Europe would increase its reduction effort from 0.4 percent to 1.5 percent of its 1990 CO_2 emission level, largely to the benefit of Japan, Oceania, and the United States. (In the year 2010 OECD Europe would become a potential donor).

Table 4.2 presents an assessment of the economic gains of JI in 2000 in the Base Case. Column one gives the regional CO_2 reduction costs to meet the regional reduction targets. Column two presents these costs after JI (i.e. the optimal solution). Through JI, global reduction costs fall from US$ 76 bn to US$ 8 bn, an economic gain of 90 percent.

Columns 3 and 4 indicate the necessary transfers between regions to finance the JI projects. Column 3 assumes that there are no overhead cost involved, so the transfers are equal to the CO_2 reduction costs. In column 4 it is assumed that overhead costs of JI projects are 50 percent of the CO_2 reduction costs. Columns 5 and 6 present an assessment of the regional total costs (direct reduction costs and JI transfers), assuming no overhead and 50 percent overhead, respectively. The last two columns present the regional economic gains of JI in percentages of their initial reduction costs. The gains to donor countries are considerable (81 to 91 percent, on average 85 percent); when assuming 50 percent overhead on JI projects the gains are still considerable (77 to 87 percent).

Table 4.2: Direct CO_2 reduction costs to meet the regional targets without reducing emissions outside the region (second column in mn 1990 US $); Direct CO_2 reduction costs to meet the regional targets after JI (third column in mn 1990 US $); Trade costs with shares of donor countries equal to shares of the direct costs in column two, in the case of host countries the trade costs are equal to the direct cost without JI minus the direct costs after JI (fourth column); Trade costs are equal to the fourth column, except for non-OECD countries which are assumed to receive overhead cost of 50% more than calculated in the fourth column (fifth column); Total costs are defined as the sum of the direct costs after JI and the trade costs in the no overhead resp. 50% overhead case (sixth resp. seventh column in mn 1990 US $).

Regions	Direct costs in 2000		Trade costs in 2000		Total costs in 2000		Gains in 2000	
	without JI	after JI	no overhead	50% overhead	no overhead	50% overhead	no overhead	50% overhead
	mn US $	mn US $	mn US $	mn US $	mn US $	mn US $	percent	percent
Canada	-	74	-74	-74	-	-	-	-
Japan	37069	292	3324	4714	3616	5006	90	86
Oceania	32092	54	2878	4081	2931	4135	91	87
USA	7141	724	640	908	1365	1632	81	77
OECD Europe	104	1149	-1046	-1046	104	104	-	-
CIS	-	1565	-1565	-2348	-	-783	-	-
Eastern Europe	-	763	-763	-1144	-	-381	-	-
Africa	-	51	-51	-76	-	-25	-	-
China+C.P.Asia	-	2357	-2357	-3535	-	-1178	-	-
East Asia	-	353	-353	-529	-	-176	-	-
India+S.Asia	-	207	-207	-310	-	-103	-	-
Latin America	-	166	-166	-250	-	-83	-	-
Middle East	-	261	-261	-391	-	-130	-	-
OECD	76406	2294	5722	8583	8016	10877	90	86
CEIT	-	2328	-2328	-3491	-	-1164	-	-
LDC	-	3395	-3395	-5092	-	-1697	-	-
World	76406	8016	-0	-0	8016	8016	90	90

Table 4.3 presents the economic gains of JI for the year 2010. Global economic gains are 76 percent. Economic gains to donor countries are 58 to 83 percent, on average 65 percent (50 to 75 percent with overhead). Note that Eastern Europe has turned into a potential *donor*.

Table 4.3: Direct CO_2 reduction costs to meet the regional targets without reducing emissions outside the region (second column in bn 1990 US \$); Direct CO_2 reduction costs to meet the regional targets after JI (third column in bn 1990 US \$); Trade costs with shares of donor countries equal to shares of the direct costs in column two, in the case of host countries the trade costs are equal to the direct cost without JI minus the direct costs after JI (fourth column); Trade costs are equal to the fourth column, except for non-OECD countries which are assumed to receive overhead cost of 50% more than calculated in the fourth column (fifth column); Total costs are defined as the sum of the direct costs after JI and the trade costs in the no overhead resp. 50% overhead case (sixth resp. seventh column in bn 1990 US \$).

Regions	Direct costs in 2010		Trade costs in 2010		Total costs in 2010		Gains in 2010	
	without JI	after JI	no overhead	50% overhead	no overhead	50% overhead	no overhead	50% overhead
	bn US $	bn US $	bn US $	bn US $	bn US $	bn US $	percent	percent
Canada	0	1	-1	-1	0	0	-	-
Japan	192	5	31	46	35	51	82	74
Oceania	107	1	17	25	19	27	83	75
USA	100	12	16	24	28	36	73	65
OECD Europe	67	12	11	16	22	28	67	59
CIS	0	21	-21	-32	0	-10	-	-
Eastern Europe	41	11	7	10	17	20	58	50
Africa	-	2	-2	-3	0	-1	-	-
China+C.P.Asia	-	42	-42	-64	0	-21	-	-
East Asia	-	5	-5	-7	0	-2	-	-
India+S.Asia	-	4	-4	-6	0	-2	-	-
Latin America	-	2	-2	-4	0	-1	-	-
Middle East	-	3	-3	-5	0	-2	-	-
OECD	467	31	74	111	104	141	78	70
CEIT	41	32	-15	-22	17	10	58	76
LDC	-	59	-59	-89	-	-30	-	-
World	508	122	0	0	122	122	76	76

The costs of emission reductions for OECD countries could be reduced by 85 percent in 2000 and 70 percent in 2010 with JI compared to a situation without JI.

4.3 Scenario results for the period 1990-2100; the Baseline-Medium scenario

The EE model can calculate for each region, sector and energy function the demand for each energy carrier. In this section the results will be presented based on the assumptions that are used for the Baseline-Medium Scenario as described in several Tables in Appendix E. For most world regions the socio-economic and demographic assumptions are taken from the IS92a scenario of the IPCC (see Legget *et al.*.,1994). For Eastern Europe and CIS assumptions are used of the World Bank (1993). The fuel price scenarios are the results of calculations of the Edmonds-Reilly model using the IS92a scenario assumptions of the IPCC.

In Appendix F information is given on the Autonomous Energy Efficiency Improvements as calculated by the EE model.

The overall results when applying the EE model for this scenario are summarized in Figures 4.5 (Energy intensities), Figure 4.6 (Secondary Energy Use) and Figure 4.7 (CO_2 emissions).

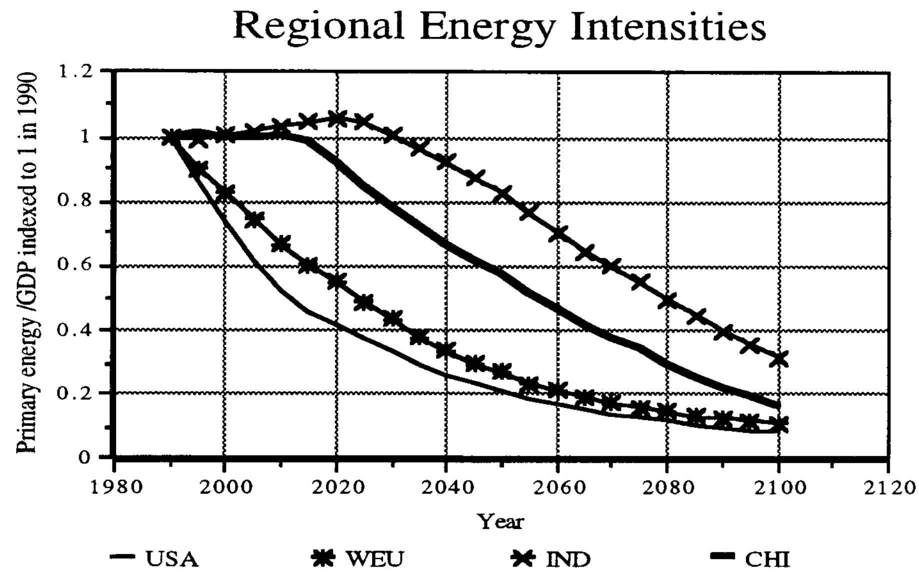
More detailed results are presented in Appendix G; for each region total secondary end-use energy is broken down firstly by energy carrier and secondly by sector.

Figure 4.5 shows the developments of the energy intensity for the USA, OECD Europe, India+South Asia and China+C.P. Asia as calculated by the Energy -Economy model. The energy intensity increases in India+S.Asia and China+C.P. Asia due to the booming demand for end-use energy in the residential sector. In 1990, end-use energy demand in the residential sector accounts for more than 40% of the total regional end-use energy demand. In both regions the energy intensity in the residential sector declines after 2030, resulting in an overall decline of the energy intensity.

Figure 4.5 also shows that the reduction of the energy intensity is higher in the OECD regions than in developing regions. This is due to declining energy intensities in the residential sector in the OECD regions compared to increasing energy intensities in developing regions.

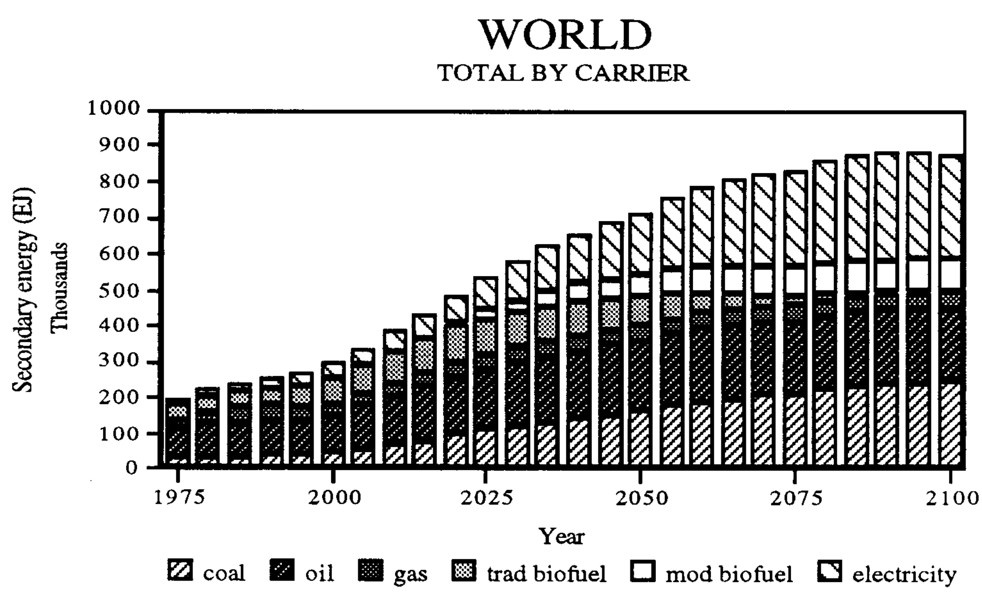
Also it can be seen from Figure 4.5 that in the Baseline-Medium Scenario in the 1990-2100 period the energy intensity in the USA and OECD-Europe only decline (dominated by declining energy intensities of the industrial and the transport sector). The decline in USA is somewhat stronger due to the fact that the overall growth of the economy in the 1990-2025 period is higher compared to OECD Europe. Still, it can be seen that the energy intensities of the USA and OECD-Europe converge.

Figure 4.5: Regional energy Intensities of USA, OECD Europe, India+S.Asia and China+C.P.Asia over the 1990-2100 period



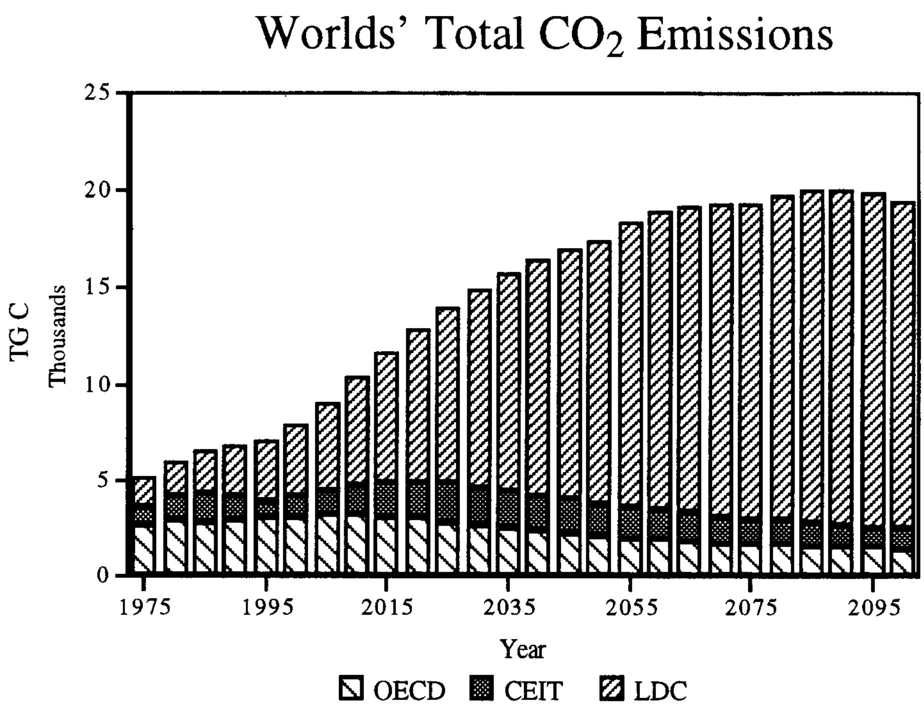
By aggregating secondary energy use over all the regions and sectors, global energy demand can be calculated. An illustration is given below in Figure 4.6 of the global energy demand per energy carrier for the 1975-2100 period. Figure 4.6 shows that total end-use energy demand rises from 200 EJ in 1975 to 900 EJ in 2100. Also it can be seen that traditional fuelwood is assumed to phase out almost completely by the year 2080.

Figure 4.5: Total worlds' energy demand per energy carrier over the 1970-2100 period



The fossil energy carriers determine the total worlds' emission pattern over time. This is presented for three clusters of regions (as defined in Section 4.2). Figure 4.6 illustrates that global emissions rise from 5,000 Tg C to almost 20,000 Tg. Also it can be seen that the share of CO_2 emissions of LDC increases sharply after 2000 due to the expansion of large economies like China + C.P. Asia and India+S.Asia.

Figure 4.6: Total worlds' CO_2 emissions for three regions; OECD , Countries with economies in transition (CEIT) and Less Developed Countries (LDC) over the 1970-2100 period.



5. Conclusions and Recommendations

In Section 4.1 cost curves are presented for the years 1990, 2000 and 2010. Although the results are subject to uncertainty, it can be seen that the EE model enables a regional comparison of marginal investment cost functions for different target years, given a set of scenario assumptions. In Section 4.2 these investment cost curves are used for a global assessment of the potential of the instrument Joint Implementation.

From the results presented in 4.2 the following can be concluded. First, the potential of JI is calculated to be 80 percent in 2000 and 65 percent in the year 2010. In other words, for the years 2000 and 2010, respectively 80 percent and 65 percent of the necessary emission reductions to meet the targets for each region could be more cheaply accomplished abroad. Second, the costs of emission reductions for OECD countries could be reduced by 85 percent in 2000 and 70 percent in 2010 with JI compared to a situation without JI. Third, even if LDCs would take on own goals for the year 2010 (thus carrying out the cheapest reduction measures themselves) the costs for OECD would be 30 percent lower with JI than without JI. Fourth, from the calculations it can be seen that Western Europe in the year 2000, would not be a potential *donor* of JI projects, but a potential *host.* In the optimal case Western Europe would increase its reduction effort from 0.4 percent to 1.5 percent of its 1990 emission level, largely to the benefit of Japan, Oceania and the United States. Given the level of uncertainty surrounding the scenario assumptions this result (host instead of donor) is not particularly robust. Yet, it is quite clear that in comparison to other OECD regions, Western Europe's gains from JI are less. In other words, in a world market for JI projects, Western Europe could face strong competition. (N.B. In the year 2010 Western Europe would become a potential donor).

Finally, in Section 4.3 results of calculations of the EE model are presented using the baseline-medium scenario assumptions. Most important conclusion is that end-use energy will rise by 375 percent in the year 2100. CO_2 emissions will increase by 200 percent in the 1990-2100 period. In 2100 the largest amount of emissions come from lower developed countries.

Concerning the recommendations the following activities are considered as improvements of the EE model. First, regional energy consumption estimates may be improved by including fuel depletion via a simple function as reported in Edmonds-Reilly (1985) and the effects of trade on prices energy. The latter activity may be done by incorporating a simple global fuel trade model based on input-output modelling. Secondly, developing an estimation procedure to improve the parameter set of the model by using Maximum Likelihood estimations will yield results easier to communicate. A paper is in preparation about this subject. Lastly, investigate the irreversibility problem as detected in

Section 3.5; no change in the energy intensity (before AEEI and PIEEI corrections) in a period of declining activities.

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Appendix A: Cost Calculus

Cost per unit of energy in equation [8] are determined by

$$c_{f,t,s,h} = a_{f,s,h} \cdot \frac{I_{f,s,h}}{\left(LF_{s,h} \cdot 8760 \cdot 0{,}036 \cdot \varepsilon_{f,t,s,h}\right)} + \left(\frac{p}{\varepsilon}\right)_{f,t,s,h} + OM_{f,s,h} \qquad [12]$$

with

a = annuity factor

LF = Load Factor

OM = operation and maintenance costs per unit of useful energy

p = price of secondary energy carriers

ε = conversion efficiency of secondary energy carrier to end-use energy

Costs per unit of energy per energy carrier consist of three parts: annualized investments, prices corrected for energy conversion efficiencies and operation and maintenance costs. Investments per unit of energy per fuel type are annualized by multiplication of investments by the annuity factor given by the following formula:

$$a_{f,s,j} = \frac{r}{1-(1+r)^{-T_{f,s,j}}} \qquad [13]$$

with

r = interest rate

T = technical lifetime of equipment using energy carrier for energy function j in sector s

The second part of the cost function consists of the actual prices of the fuel type being used and should be corrected for the conversion losses during conversion of secondary fuels to end-use energy functions. The last term in equation [12] refers to the operational and maintenance costs in using a certain secondary energy carrier. Be aware that all these cost elements are calculated in monetary values per unit of end-use energy. Further details can be found in de Vries *et. al.* (1994).

Appendix B: Regional CO_2 Investment Cost Curves

In section 2.4 the investment curve as included in the model has been presented. However, in order to compute the curves two important aspect have to be taken into account. First, as time evolves the reduction factor in each sector will increase. The remaining options to reduce the maximum attainable reduction factor will decrease over time. Second, as the reduction factor increases it is implied that revenues are generated because fuel costs are lower than if no energy conservation measures are taken. To compare the investment cost functions of e.g. the ICARUS database (Blok *et. al.,* 1990) including sectoral cost curves for 1990, and the cost curves as implemented in the Energy-Economy model, the following transformations procedure has been followed:

Procedure 1:

1. Transform $b_{s,j}^{1970}$ into $b_{s,j}^{1990} = \left(b_{s,j}^{1970} - \beta_{1990,s,j}\right) / \left(1 - \beta_{1990,s,j}\right)$

with

$b_{s,j}^{t}$ = possible percentage reduction in year t in sector s for energy function j **in addition to** already achieved reduction in that year

$\beta_{t,s,j}$ = percentage reduction in year t in sector s for energy function j

2. Compute $I(b_{s,j}^{1990}) = I(b_{s,j}^{1970}) - I(\beta_{1990,s,j}) - \left(b_{s,j}^{1970} - \beta_{1990,s,j}\right) \cdot c_{1990,s,j} \cdot P_s$

with

I = Net investments

3. Plot $I(b_{s,j}^{1990})$ and $b_{s,j}^{1990}$

Step 1 accounts for reductions achieved compared to 1970. For example, one could reduce energy demand by at most 90 percent and in 1990 already 50% (in terms of reductions compared to 1970 savings) has been achieved, therefore 40% point still can be achieved which implies that in 1990 still 80% (in terms of reductions compared to 1990 savings) of energy demand can be reduced. Step 2 adjusts investment costs for net investments done in the period 1970-1990. Step 3 is the graphical output of the procedure 1.

Marginal investment cost curves per unit of end-use energy can be expressed per unit of CO_2 removed and can be created in the following way

Procedure 2:

1. Transform $b_{s,j}^{1990}$ into $bb_{s,j}^{1990} = b_{s,j}^{1990} \cdot CO2_{1990,s,j}$

with

$bb_{s,j}^{t}$ = possible removal of tonnes of CO_2

2. Transform $d\,I_{s,j}^{1990} / d\,b_{s,j}^{1990}$ into $II_{s,j}^{1990} = \dfrac{d\,I_{s,j}^{1990}}{d\,b_{s,j}^{1990}} \cdot \dfrac{AE_{1990,s,j} \cdot (1-\beta_{1990,s,j})}{CO2_{1990,s,j}}$

with

$d\,I_{s,j}^{t} / d\,b_{s,j}^{t}$ = marginal investments per unit of end-use energy in year t of energy function j in sector s

$II_{s,j}^{t}$ = marginal investments per tonne of CO_2 removed in year t due to use energy function j in sector s

3. Plot $d\,II_{s,j}^{1990}$ ($bb_{s,j}^{1990}$) and $bb_{s,j}^{1990}$

Step 1 states transforms the variable b equal to the possible percentage reduction of end-use energy in year t in sector s for energy function j to tonnes of CO_2 removed related to that energy function in sector s in year t. Step 2 transforms marginal investments per unit of end-use energy to marginal investments per ton of CO_2 removed related to energy function j in sector s in 1990 (or year t). Step 3 is the graphical output of the procedure 2 and is illustrated by the two graphics on the top of Figure 2.6. Eqn. [14] states that for year t the marginal investment costs in sector s and energy function j costs per ton CO_2 removed is equal to the marginal investment cost curve (see footnote on page 15 including the transformed β) minus in the past generated revenues due to end-use energy conservation or

$$\frac{d\,I_{s,j}^{1990}(bb_{s,j}^{1990})}{d\,bb_{s,j}^{1990}} \cdot \frac{AE_{1990,s,j} \cdot (1-\beta_{1990,s,j})}{CO2_{1990,s,j}} = \Delta_{s,j} \cdot \left(\left(B_{s,j} - \frac{bb_{s,j}^{1990}}{CO2_{1990,s,j}} \right)^{-2} - B_{s,j}^{-2} \right) - c_{1990,s,j} \cdot P_s \quad [14]$$

with

$$\Theta_{s,j} = \frac{\phi_{s,j}}{\alpha_{s,j} + (t - t_0)^{\delta_{sj}}}$$ the multiplication factor of the investment cost curve and

$$c_{t,s,j} = \sum_f c_{f,t,s,j} \cdot \frac{\alpha_{f,t,s,j}}{\varepsilon_{f,t,s,j}}$$ the average cost price per unit of end-use energy for sector s

The inverse of Eqn. [14] is illustrated by the bottom graphic of Figure 2.6 and in calculus is equal to

$$bb_{s,j}^{1990} = CO2_{1990,s,j}\left(B_{s,j} - \left(\frac{\Pi_{s,j}^{1990} + c_{1990,s,j} \cdot P_s}{\Theta_{s,j}} - \frac{1}{B_{s,j}^2}\right)^{-1/2}\right) \qquad [15]$$

Interpretation of Eqn. [15] is that if in 1990 in sector s in the case of energy function j agents are at the most willing to invest Π US dollars per tonne CO_2 removed, bb ton CO_2 will actually be removed. The variable Π can therefore be interpreted as the shadow price for CO_2 removal. Therefore aggregation of all CO_2 reductions over all sectors and energy functions results in a relationship between marginal investments agents are willing to invest and the corresponding level of CO_2 removal or

$$bb^{1990} = \sum_s \sum_j bb_{s,j}^{1990} \qquad [16]$$

This is presented in Figure 2.7 as well as the inverse cumulative version of Eqn. [16].

Appendix C: Model Parameters

Table C1: Parameters for Eqn. [1] in the industrial sector for the energy functions heat and electricity

	Industry_Heat				Industry_Electricity			
	ξ_1	ξ_2	ξ_3	ξ_{lim}	ξ_1	ξ_2	ξ_3	ξ_{lim}
Africa	5,9E-09	0,0E+00	1,8E-04	2,0E-09	-1,9E-09	1,8E-11	5,3E-04	2,0E-10
Asia	7,7E-09	0,0E+00	7,4E-04	2,0E-09	9,1E-10	3,3E-12	4,4E-04	2,0E-10
Canada	1,1E-08	0,0E+00	1,4E-04	2,0E-09	-8,7E-09	3,8E-12	2,1E-04	2,0E-10
China+C. P. Asia	1,2E-07	0,0E+00	8,3E-05	2,0E-09	9,5E-09	5,6E-12	5,5E-04	2,0E-10
CIS	2,1E-08	0,0E+00	2,9E-04	2,0E-09	3,6E-09	0,0E+00	6,2E-05	2,0E-10
E. Europe	4,4E-08	0,0E+00	8,4E-04	2,0E-09	5,3E-09	0,0E+00	1,9E-05	2,0E-10
India	2,1E-08	0,0E+00	1,9E-04	2,0E-09	3,4E-09	2,4E-11	7,5E-04	2,0E-10
Japan	3,5E-08	0,0E+00	5,0E-04	2,0E-09	1,1E-09	2,5E-13	8,8E-05	2,0E-10
L.America	-7,4E-09	1,5E-11	6,7E-04	2,0E-09	-3,6E-09	6,1E-12	4,1E-04	2,0E-10
M. East	1,3E-06	0,0E+00	5,1E-03	2,0E-09	2,7E-06	0,0E+00	7,7E-03	2,0E-10
Oceania	3,5E-09	0,0E+00	3,3E-05	2,0E-09	-4,3E-08	1,0E-11	2,6E-04	2,0E-10
USA	5,6E-08	0,0E+00	4,1E-04	2,0E-09	-4,4E-10	7,5E-13	1,2E-04	2,0E-10
W. Europe	6,9E-09	0,0E+00	2,0E-04	2,0E-09	-8,1E-09	2,1E-12	1,9E-04	2,0E-10

Table C2: Parameters for Eqn. [1] in the transport sector for the energy functions heat and electricity

	Transport_Heat				Transport_Electricity			
	ξ_1	ξ_2	ξ_3	ξ_{lim}	ξ_1	ξ_2	ξ_3	ξ_{lim}
Africa	1,5E-04	1,3E-05	8,0E-02	5,0E-05	2,6E-06	2,2E-06	4,6E-01	5,0E-08
Asia	4,2E-04	2,1E-05	4,8E-02	5,0E-05	2,8E-08	1,0E-06	9,7E-01	5,0E-08
Canada	8,7E-05	1,3E-05	1,3E-01	5,0E-05	-3,2E-07	1,9E-06	1,2E+00	5,0E-08
China+C. P.Asia	7,2E-04	2,7E-05	3,7E-02	5,0E-05	2,3E-06	2,1E-06	4,7E-01	5,0E-08
CIS	5,5E-04	2,4E-05	4,2E-02	5,0E-05	3,6E-05	6,6E-06	1,6E-01	5,0E-08
E. Europe	1,4E-04	1,3E-05	8,2E-02	5,0E-05	3,5E-06	2,5E-06	4,2E-01	5,0E-08
India	4,9E-04	2,3E-05	4,4E-02	5,0E-05	5,7E-06	2,9E-06	3,4E-01	5,0E-08
Japan	8,9E-05	1,1E-05	1,1E-01	5,0E-05	3,3E-06	2,7E-06	4,4E-01	5,0E-08
L. America	1,8E-04	1,4E-05	7,3E-02	5,0E-05	4,5E-07	1,4E-06	7,6E-01	5,0E-08
M. East	7,7E-04	2,8E-05	3,6E-02	5,0E-05	3,9E-07	1,3E-06	7,7E-01	5,0E-08
Oceania	4,6E-05	9,2E-06	1,7E-01	5,0E-05	-5,2E-08	2,0E-06	1,0E+00	5,0E-08
USA	7,9E-05	1,4E-05	1,5E-01	5,0E-05	-8,6E-07	2,4E-06	1,6E+00	5,0E-08
W. Europe	3,6E-05	7,5E-06	1,7E-01	5,0E-05	1,2E-06	2,2E-06	6,5E-01	5,0E-08

Note: ξ_1, ξ_{lim} in US 1990 $ per Pjoule; ξ_2 in population sizeper Pjoule; ξ_3 in population size per US 1990 $

Table C3: Parameters for Eqn. [1] in the residential sector for the energy functions heat and electricity

	Residential_Heat				Residential_Electricity			
	ξ_1	ξ_2	ξ_3	ξ_{lim}	ξ_1	ξ_2	ξ_3	ξ_{lim}
Africa	-6,9E-09	2,0E-11	1,5E-03	2,0E-10	-2,7E-09	7,3E-12	8,9E-04	2,0E-10
Asia	-2,8E-09	1,9E-11	1,5E-03	2,0E-10	-8,8E-10	2,3E-12	3,8E-04	2,0E-10
Canada	1,1E-08	0,0E+00	1,4E-04	2,0E-10	-3,6E-09	7,2E-13	1,0E-04	2,0E-10
China+C. P.Asia	1,2E-08	1,6E-11	5,7E-04	2,0E-10	-4,0E-10	7,3E-12	3,4E-04	2,0E-10
CIS	-1,6E-08	7,4E-12	5,4E-04	2,0E-10	-6,0E-10	3,0E-13	1,7E-04	2,0E-10
E. Europe	5,3E-09	8,9E-12	5,9E-04	2,0E-10	-2,8E-09	5,2E-12	2,5E-04	2,0E-10
India	-4,5E-10	1,5E-11	1,3E-03	2,0E-10	-1,8E-09	1,1E-11	3,5E-04	2,0E-10
Japan	-1,8E-09	4,0E-13	1,8E-04	2,0E-10	-2,0E-09	3,0E-13	1,3E-04	2,0E-10
L.America	-6,1E-09	9,3E-12	1,3E-03	2,0E-10	-2,4E-09	2,1E-12	2,6E-04	2,0E-10
M. East	-4,7E-08	3,1E-11	1,0E-03	2,0E-10	-3,9E-09	2,3E-12	2,6E-04	2,0E-10
Oceania	-6,9E-07	9,8E-11	7,2E-04	2,0E-10	-3,3E-08	5,0E-12	2,9E-04	2,0E-10
USA	1,2E-08	0,0E+00	1,5E-04	2,0E-10	-1,7E-08	2,0E-12	1,6E-04	2,0E-10
W. Europe	5,9E-10	3,1E-13	5,6E-05	2,0E-10	-6,1E-09	9,1E-13	1,9E-04	2,0E-10

Table C4: Parameters for Eqn. [1] in the commercial sector for the energy functions heat and electricity

	Commercial_Heat				Commercial_Electricity			
	ξ_1	ξ_2	ξ_3	ξ_{lim}	ξ_1	ξ_2	ξ_3	ξ_{lim}
Africa	3,9E-10	3,1E-13	4,5E-04	2,0E-10	-4,4E-10	3,3E-12	3,5E-04	2,0E-10
Asia	-6,5E-08	2,7E-10	1,2E-02	2,0E-10	-7,3E-10	3,8E-12	7,7E-04	2,0E-10
Canada	5,8E-09	0,0E+00	1,1E-04	2,0E-10	-9,6E-10	3,9E-13	8,0E-05	2,0E-10
China+C. P.Asia	5,3E-09	0,0E+00	3,8E-04	2,0E-10	3,9E-10	9,3E-12	3,3E-04	2,0E-10
CIS	1,3E-08	0,0E+00	2,7E-04	2,0E-10	1,3E-09	2,3E-13	8,4E-05	2,0E-10
E. Europe	1,0E-09	0,0E+00	1,7E-03	2,0E-10	-1,0E-10	1,1E-12	1,7E-04	2,0E-10
India	1,3E-09	0,0E+00	7,3E-03	2,0E-10	-2,7E-10	8,3E-12	3,4E-04	2,0E-10
Japan	-4,3E-09	8,5E-13	2,3E-04	2,0E-10	-7,0E-10	1,0E-13	7,6E-05	2,0E-10
L.America	-4,8E-11	1,2E-14	1,7E-04	2,0E-10	-1,2E-09	1,1E-12	2,0E-04	2,0E-10
M. East	-1,3E-09	9,3E-13	6,2E-04	2,0E-10	-8,6E-10	6,7E-13	2,7E-04	2,0E-10
Oceania	-8,8E-07	1,2E-10	7,8E-04	2,0E-10	-2,3E-09	3,7E-13	1,1E-04	2,0E-10
USA	8,9E-09	0,0E+00	1,6E-04	2,0E-10	-9,8E-09	1,1E-12	1,2E-04	2,0E-10
W. Europe	-2,5E-08	4,4E-12	3,5E-04	2,0E-10	-7,6E-10	1,5E-13	7,7E-05	2,0E-10

Table C5: Parameters for Eqn. [1] in the residential sector for the energy functions heat and electricity

	Other_Heat				Other_Electricity			
	ξ_1	ξ_2	ξ_3	ξ_{lim}	ξ_1	ξ_2	ξ_3	ξ_{lim}
Africa	2,8E-10	5,8E-16	1,7E-06	2,0E-10	1,4E-10	4,3E-16	2,3E-06	2,0E-12
Asia	2,3E-10	5,4E-16	1,9E-06	2,0E-10	1,4E-10	4,3E-16	2,3E-06	2,0E-12
Canada	5,4E-11	3,2E-16	3,8E-06	2,0E-10	7,1E-11	3,6E-16	3,4E-06	2,0E-12
China+C.P.Asia	3,1E-09	1,8E-15	5,5E-07	2,0E-10	7,6E-10	9,3E-16	1,1E-06	2,0E-12
CIS	2,8E-09	1,8E-15	5,9E-07	2,0E-10	2,1E-10	5,2E-16	2,0E-06	2,0E-12
E. Europe	3,7E-09	2,0E-15	5,1E-07	2,0E-10	4,3E-10	7,1E-16	1,4E-06	2,0E-12
India	1,2E-11	1,7E-16	5,9E-06	2,0E-10	1,4E-10	4,3E-16	2,4E-06	2,0E-12
Japan	2,3E-10	5,8E-16	2,0E-06	2,0E-10	-1,2E-12	1,2E-16	1,1E-05	2,0E-12
L.America	3,5E-10	6,5E-16	1,6E-06	2,0E-10	1,6E-10	4,5E-16	2,3E-06	2,0E-12
M. East	1,7E-10	4,7E-16	2,2E-06	2,0E-10	8,6E-11	3,6E-16	2,9E-06	2,0E-12
Oceania	3,2E-10	6,7E-16	1,7E-06	2,0E-10	1,7E-11	2,2E-16	5,6E-06	2,0E-12
USA	1,2E-10	4,5E-16	2,8E-06	2,0E-10	1,3E-11	2,1E-16	6,2E-06	2,0E-12
W. Europe	1,7E-10	5,1E-16	2,3E-06	2,0E-10	1,7E-11	2,2E-16	5,6E-06	2,0E-12

Table C6: Substitution elasticity in the MNL-function

	Industry	Transport	Residential	Commercial	Other
θ	1.00	1.75	1.50	2.00	1.50

Table C7: Depreciation period of the end-use, producing capital (year)

	Industry		Transport		Residential		Commercial		Other	
	heat	elec.	heat	elec.	heat	elec.	heat	elec.	heat	elec.
Canada	10	10	6	10	15	5	15	5	10	10
USA	10	10	6	10	15	5	15	5	10	10
L.America	10	10	8	15	15	7	15	7	10	10
Africa	15	15	10	20	15	10	15	10	10	10
W. Europe	10	10	6	10	15	5	15	5	10	10
E. Europe	10	10	8	15	15	7	15	7	10	10
CIS	10	10	8	15	15	7	15	7	10	10
M. East	10	10	8	15	15	7	15	7	10	10
India	15	15	10	20	15	10	15	10	10	10
China+C.P.Asia	12	12	10	20	15	10	15	10	10	10
Asia	10	10	8	15	15	7	15	7	10	10
Oceania	10	10	6	10	15	5	15	5	10	10
Japan	10	10	6	10	15	5	15	5	10	10

Table C8: Fraction relative to starting year to which the marginal energy intensity is decreased (period 1971-1990)

	Industry		Transport		Residential		Commercial		Other	
	heat	elec.	heat	elec.	heat	elec.	heat	elec.	heat	elec.
Canada	0.80	0.80	0.80	0.70	0.65	0.90	0.85	0.85	1.00	0.80
USA	0.85	0.90	0.90	0.30	0.85	0.90	0.85	0.85	0.50	0.55
L.America	0.90	0.90	0.60	0.50	1.00	1.00	0.90	0.95	1.00	0.75
Africa	0.90	0.90	0.80	0.70	1.00	1.00	0.95	1.00	1.00	1.00
W. Europe	0.50	0.80	0.85	0.70	0.45	0.95	0.85	0.80	0.35	0.95
E. Europe	0.99	0.99	0.30	1.00	0.99	0.99	0.99	0.99	0.99	0.99
CIS	0.95	0.95	0.40	0.35	1.00	0.99	0.65	0.90	0.60	1.00
M. East	0.90	0.90	0.40	0.50	0.90	1.00	0.90	0.90	1.00	1.00
India	0.94	1.00	0.50	0.50	0.95	1.00	0.80	1.00	1.00	1.00
China+C.P. Asia	0.40	1.00	0.65	0.50	0.75	0.90	0.75	1.00	0.65	0.70
Asia	0.85	0.90	0.80	0.50	0.85	0.85	0.85	0.90	1.00	0.85
Oceania	0.85	0.75	1.00	1.00	0.85	0.85	0.85	0.85	0.70	1.00
Japan	0.85	0.85	0.60	0.65	0.85	0.95	0.85	0.90	0.75	0.75

Table C9: Limit value to which the energy intensity is decreased (period 1990-2100) (E-09 PJ/US$-1990 or PJ/Cars);Maximum fraction of energy conservation B in investment cost function (fraction)

	Industry		Transport		Residential		Commercial		Other	
	heat	elec.	heat	elec.	heat	elec.	heat	elec.	heat	elec.
Limit value	2.0	0.2	50000	0.2	0.2	0.1	0.1	0.1	0.1	0.002
B (cost)	0.9	0.9	0.99	0.8	0.9	0.9	0.0	0.9	0.9	0.4

Table C9: Relaxation time of the decrease in marginal energy intensity (period 1990-2100) (year)

	CAN	USA	LAM	AFR	WEU	EEU	CIS	MEA	IND	CHI	SEA	OCE	JAP
years	150	150	120	120	150	100	100	120	120	100	120	150	150

Table C10: Scaling factor for conservation cost curves (US$-1990 / GJ)

	Industry		Transport		Residential		Commercial		Other	
	heat	elec.	heat	elec.	heat	elec.	heat	elec.	heat	elec.
Canada	120	100	300	50	150	100	50	50	200	10
USA	120	130	300	50	100	100	70	100	40	5
L.America	100	100	100	100	150	200	50	100	200	5
Africa	200	250	200	200	200	150	100	300	150	200
W. Europe	120	130	200	200	50	150	50	100	150	8
E. Europe	100	200	50	200	150	100	70	100	100	100
CIS	100	100	150	50	70	70	100	50	10	200
M. East	100	100	150	1200	150	100	100	100	200	200
India	120	200	200	1200	220	250	100	300	200	200
China+C.P. Asia	50	200	200	1200	200	150	100	300	200	100
Asia	100	200	200	1200	150	200	80	100	300	100
Oceania	120	130	600	1200	100	100	50	100	10	200
Japan	120	250	200	100	200	200	70	140	50	20

Table C11: Pay-back time (year)

	Industry		Transport		Residential		Commercial		Other	
	heat	elec.	heat	elec.	heat	elec.	heat	elec.	heat	elec.
Canada	3	3	0.5	5	5	5	3	3	3	3
USA	3	3	0.5	5	5	5	3	3	3	3
L.America	3	3	3	5	5	5	3	3	3	3
Africa	3	3	1	3	5	5	3	3	3	3
W. Europe	3	3	1	3	5	5	3	3	3	3
E. Europe	3	3	3	1	5	5	3	3	3	3
CIS	3	3	3	5	5	5	3	3	3	3
M. East	3	3	3	3	5	5	3	3	3	3
India	3	3	0.5	3	5	5	3	3	3	3
China+C.P. Asia	3	3	0.5	3	5	5	3	3	3	3
Asia	3	3	3	3	5	5	3	3	3	3
Oceania	3	3	0.5	3	5	5	3	3	3	3
Japan	3	3	3	5	5	5	3	3	3	3

Appendix D: Historical Price Developments

Table D.1 presents the developments of the prices of the energy carriers and the fixed value for their premium factors in the industrial and residential sector in Eastern Europe, given that in the industrial sector the cross-price-substitution elasticity is equal to 1 percent and in the residential sector equal to 1.5 percent. The second column states that, e.g. in 1970 the price of coal in the industrial sector was equal to 2.1 1990 US$ per GJ. The fourth and fifth column give information on the premium factor of gas resp. oil in the industrial and the residential sector. From Table 3.2 it can be seen in these columns that premium factors remain constant throughout the 1970-1990 period, they have been calibrated in this way by assumption. Be aware that the premium factor for oil has been fixed to one. The last two columns show the results of the multiplication of the coal price and the premium factor. This is equal to the price in the perception of the agents that make use of a certain energy carrier. It determines on this aggregated level, which market share per energy carrier to work with on the newly installed vintage. In 1970 the premium factor increased the actual price of coal by 850 percent resulting in a perceived price equal to 16 US $ per GJ.

*Table D1: Development of prices including the premium factor as input to the Multinomial Logit Function in the industrial and residential sector in Eastern Europe**

	coal	oil	gas	coal	gas	coal	gas
	price in 1990 US $ per GJ			premium factor		price * premium factor in 1990 US $ per GJ	
Industry 1970	2.1	2.5	7.0	7.5	32	16	222
Industry 1975	2.1	2.5	7.0	7.5	32	16	222
Industry 1980	2.1	2.5	3.6	7.5	32	16	115
Industry 1985	1.7	1.9	3.1	7.5	32	12	98
Industry 1990	2.3	2.2	2.2	7.5	32	17	69
Residences 1970	1.5	3.2	1.1	0.2	1.1	0.3	1.2
Residences 1975	1.7	3.2	1.1	0.2	1.1	0.3	1.2
Residences 1980	1.6	3.2	1.1	0.2	1.1	0.3	1.2
Residences 1985	2.2	2.7	0.8	0.2	1.1	0.4	0.8
Residences 1990	3.8	3.1	0.4	0.2	1.1	0.7	0.5

Note: Prices of the energy carriers come from IEA statistics, for oil, premium factors are kept constant at value 1.

*Table D2: Development of prices including the premium factor as input to the Multinomial Logit Function in the service and industrial sector in CIS**

	coal	oil	gas	coal	gas	coal	gas
	price in 1990 US $ per GJ			premium factor		price * premium factor in 1990 US $ per GJ	
Industry 1970	0.9	0.2	0.1	0.5	0.5	0.4	0.1
Industry 1975	0.9	0.2	0.1	0.5	0.5	0.4	0.1
Industry 1980	0.9	0.2	0.1	0.5	0.5	0.4	0.1
Industry 1985	1.3	0.5	0.2	0.5	0.5	0.6	0.1
Industry 1990	1.3	1.3	1.2	0.5	0.5	0.6	0.6
Residences 1970	2.6	0.5	0.3	0.2	0.0	0.5	0.0
Residences 1975	2.6	0.5	0.3	0.2	0.0	0.5	0.0
Residences 1980	2.6	0.5	0.3	0.2	0.0	0.5	0.0
Residences 1985	3.8	1.2	0.4	0.2	0.0	0.7	0.0
Residences 1990	3.8	3.4	2.7	0.2	0.0	0.7	0.0

Note: Prices of the energy carriers come from IEA statistics, for oil, premium factors are kept constant at value 1.

Appendix E: Scenario Assumptions

This Appendix contains five Tables representing the main characteristics of a scenario, called the Baseline-Medium Scenario. For most world regions the socio-economic and demographic assumptions are taken from the IS92a scenario of the IPCC (see Legget *et al*..,1994). For Eastern Europe and CIS assumptions are used of the World Bank (1993). The fuel price scenarios are the results of calculations of the Edmonds-Reilly model using the IS92a scenario assumptions of the IPCC. Table E1 gives information on the developments of GDP and population as assumed in the Baseline-Medium scenario. Table E2 gives the sectoral driving forces for the shorter time horizon (1990-2000 period). Table E3 has the same format as Table E2, but refers to the 2000-2010 period.

Table E1: Growth rate of GDP and Population for IMAGE regions over the 1990-2100 period

	GDP 1990-2000	GDP 2000-2025	GDP 2025-2050	GDP 2050-2100	POP 1990-2000	POP 2000-2025	POP 2025-2050	POP 2050-2100
	% yr^{-1}	% yr^{-1}	% yr^{-1}	% yr^{-1}	% yr^{-1}	% yr^{-1}	% yr^{-1}	% yr^{-1}
Canada	2.2	3.4	1.7	1.1	0.4	0.2	-0.1	-0.0
Japan	3.3	4.2	1.6	1.1	0.6	0.2	-0.1	-0.0
Oceania	3.3	4.2	1.6	1.1	0.6	0.2	-0.1	-0.0
USA	3.0	2.9	1.5	1.1	0.8	0.8	-0.1	-0.0
WestEur	2.2	3.4	1.7	1.1	0.4	0.2	-0.1	-0.0
CIS	-2.4	7.3	1.3	1.1	0.6	0.6	0.2	-0.0
EastEur	2.4	7.3	1.3	1.1	0.6	0.6	0.2	-0.0
Africa	0.1	3.7	2.3	2.4	2.8	4.1	1.5	0.5
China+C.P.Asia	3.6	7.6	3.2	3.0	1.4	1.4	0.3	0.1
East Asia	2.5	5.3	3.0	2.8	1.9	2.2	0.8	0.2
India+S.Asia	2.5	5.3	3.0	2.8	1.9	2.2	0.8	0.2
Lat America	0.9	3.7	2.2	2.2	1.8	2.0	0.6	0.1
Mideast	1.0	2.5	1.8	2.1	3.0	4.3	1.5	0.5
OECD	2.7	3.4	1.6	1.1	0.6	0.4	-0.1	-0.0
CEIT	-1.0	7.3	1.3	1.1	0.6	0.6	0.2	-0.0
LDC	1.8	4.7	2.6	2.5	1.9	2.5	0.8	0.3
World	1.6	2.6	1.3	1.6	1.6	2.1	0.7	0.2

Table E2: Driving forces per caput and Population; annual growth rates 1990-2000

	Pop	VA ind	Cars	Priv. Cons	VA ser	GDP
Canada	0.4	2.2	0.6	2.1	2.2	2.2
Japan	0.6	3.3	0.6	3.2	3.4	3.3
Oceania	0.6	2.9	0.5	3.3	3.0	3.3
USA	0.8	3.0	0.2	2.9	3.0	3.0
WestEur	0.4	2.2	0.2	2.2	2.2	2.2
CIS	0.6	-1.5	-4.7	-2.4	-6.2	-2.4
EastEur	0.6	2.5	1.1	2.5	3.1	2.4
Africa	2.8	0.1	-0.0	0.0	0.1	0.1
China+C.P.Asia	1.4	5.2	12.5	3.6	6.3	3.6
East Asia	1.9	2.9	9.9	2.4	3.1	2.5
India+S.Asia	1.9	3.9	4.5	2.4	3.9	2.5
Lat America	1.8	0.8	0.6	0.9	1.1	0.9
Mideast	3.0	0.9	0.7	1.0	1.2	1.0
OECD	0.6	2.7	0.3	2.7	2.7	2.7
CEIT	0.6	-0.5	-1.3	-1.2	-1.9	-1.0
LDC	1.9	2.1	3.0	1.7	2.2	1.8
World	1.6	1.6	-0.2	1.5	1.7	1.6

Table E.3: Driving forces per caput and Population; annual growth rates 2000-2010

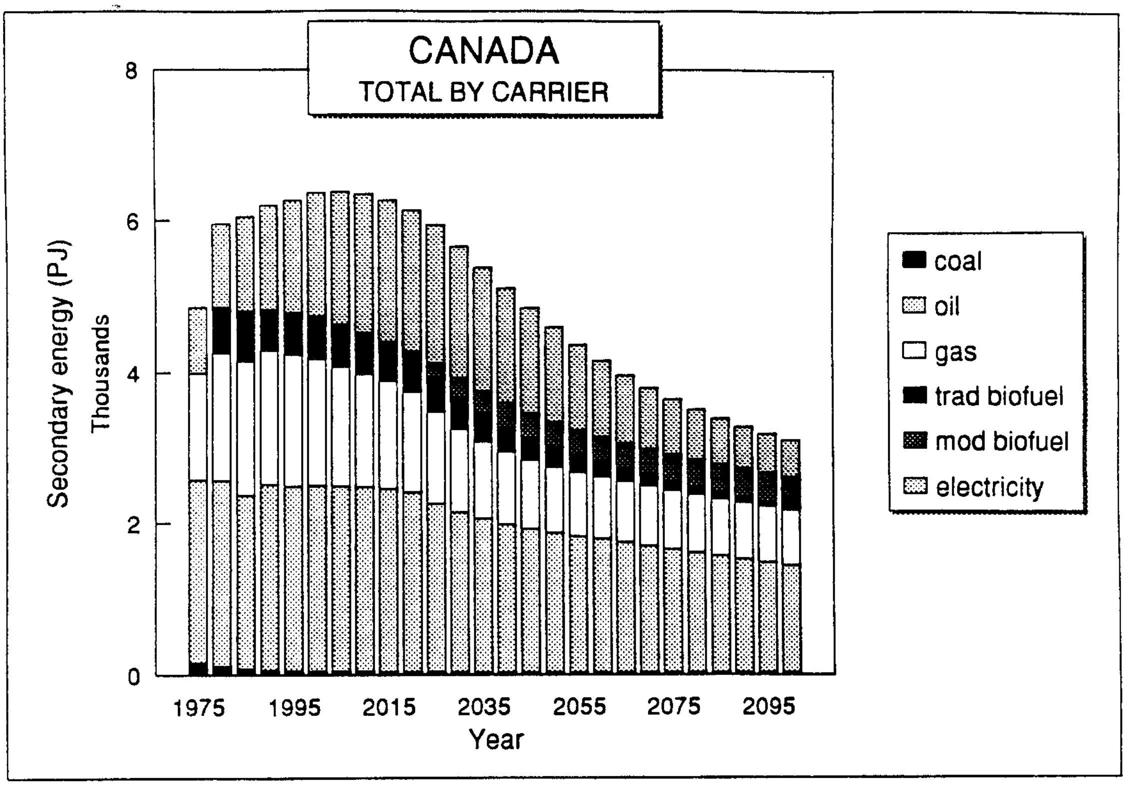
	Pop	VA ind	Cars	Priv. Cons	VA ser	GDP
Canada	0.1	2.4	0.6	2.4	2.5	2.4
Japan	0.1	3.3	0.5	3.3	3.3	3.3
Oceania	0.1	3.3	0.4	3.3	3.3	3.3
USA	0.5	2.7	0.1	2.7	2.7	2.7
WestEur	0.1	2.4	0.2	2.4	2.5	2.4
CIS	0.4	5.3	10.4	5.6	8.6	5.6
EastEur	0.4	4.8	1.9	5.6	6.6	5.6
Africa	2.9	1.1	1.0	0.7	1.1	0.7
China+C.P.Asia	0.9	6.3	5.8	4.4	6.8	4.4
East Asia	1.5	3.0	1.3	3.0	3.7	3.0
India+S.Asia	1.5	4.7	5.3	3.0	4.6	3.0
Lat America	1.3	1.6	1.2	2.0	2.3	2.0
Mideast	3.0	0.7	0.6	0.9	1.1	0.9
OECD	0.2	2.7	0.3	2.7	2.7	2.7
CEIT	0.4	5.1	5.5	5.6	7.5	5.6
LDC	1.6	2.9	2.1	2.4	3.1	2.5
World	1.4	2.0	0.3	1.9	1.9	1.9

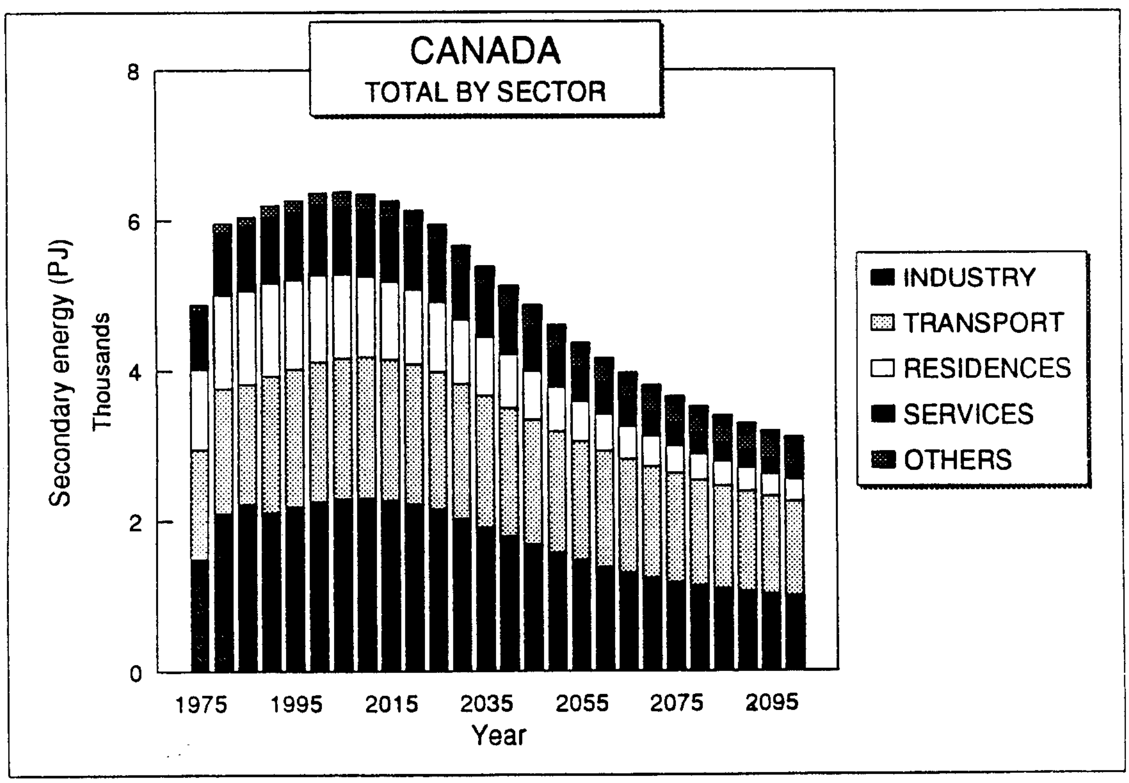
Appendix F: Scenario Results For AEEI

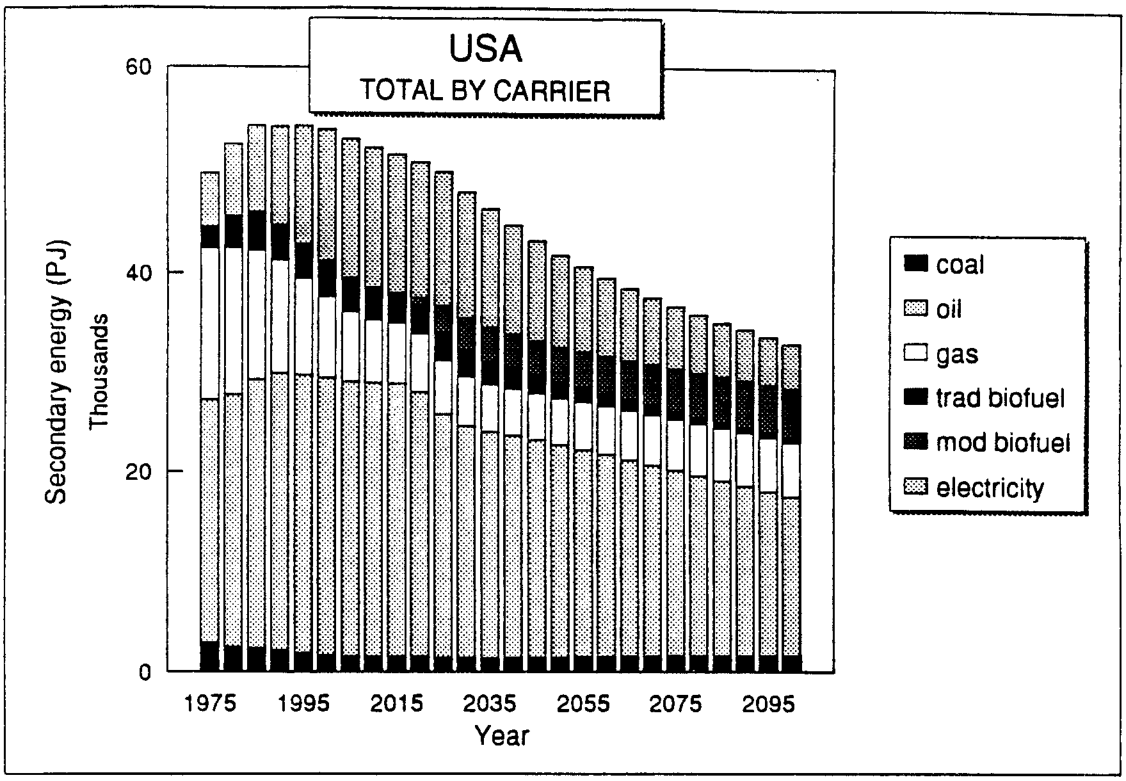
Table F1: Average AEEI in the IMAGE regions in the 1990-2100 period (%/yr)

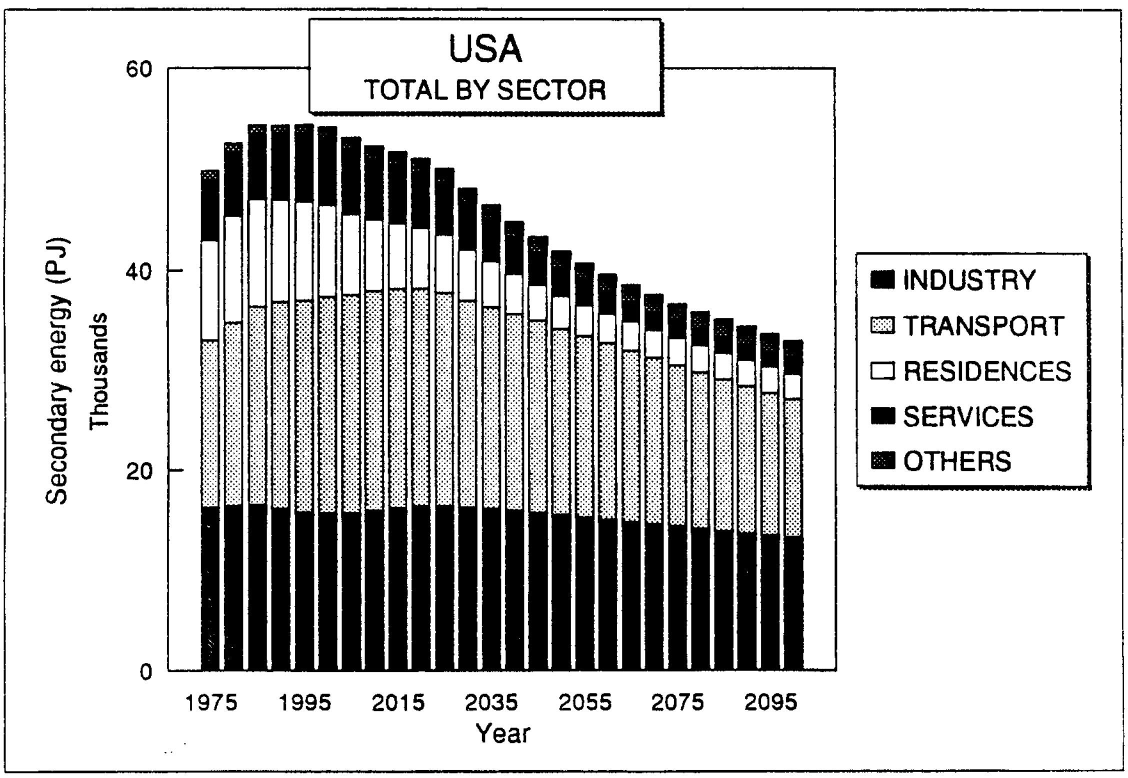
	1990 - 2010	1990 - 2010	2010 - 2025	2010 - 2025	2025 - 2050	2025 - 2050	2050 - 2100	2050 - 2100	1990 - 2100	1990 - 2100
	heat	elec	heat	elec	heat	elec	heat	elec	heat	elec
Canada	0.7	0.6	0.5	0.5	0.4	0.5	0.4	0.4	0.5	0.5
USA	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Latin America	0.7	0.5	0.6	0.6	0.5	0.6	0.4	0.6	0.5	0.6
Africa	0.6	0.5	0.6	0.7	0.5	0.6	0.5	0.5	0.6	0.6
OECD Europe	1.2	0.7	0.7	0.5	0.5	0.5	0.4	0.4	0.6	0.5
Eastern Europe	0.5	0.6	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.7
CIS	1.1	0.7	0.9	0.7	0.6	0.7	0.6	0.6	0.7	0.7
Middle East	1.0	0.4	0.8	0.6	0.6	0.6	0.3	0.6	0.6	0.6
India+S.Asia	0.7	0.4	0.7	0.6	0.6	0.6	0.5	0.6	0.6	0.6
China+C.P. Asia Region	1.4	0.5	0.7	0.7	0.5	0.7	0.6	0.7	0.7	0.7
East Asia	0.7	0.6	0.6	0.6	0.5	0.6	0.5	0.5	0.5	0.6
Oceania	0.6	0.8	0.6	0.5	0.5	0.4	0.5	0.3	0.5	0.5
Japan	0.6	0.5	0.4	0.5	0.4	0.5	0.4	0.4	0.4	0.5

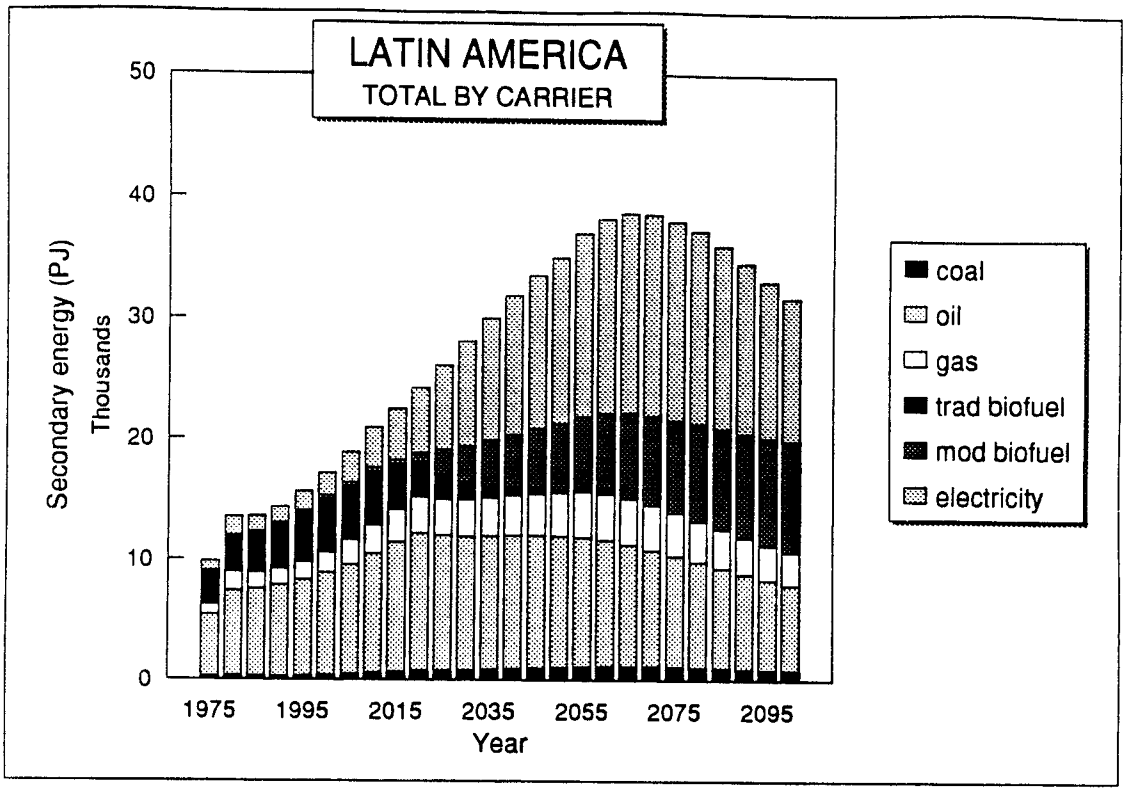
Appendix G: Scenario Results For Secondary Energy

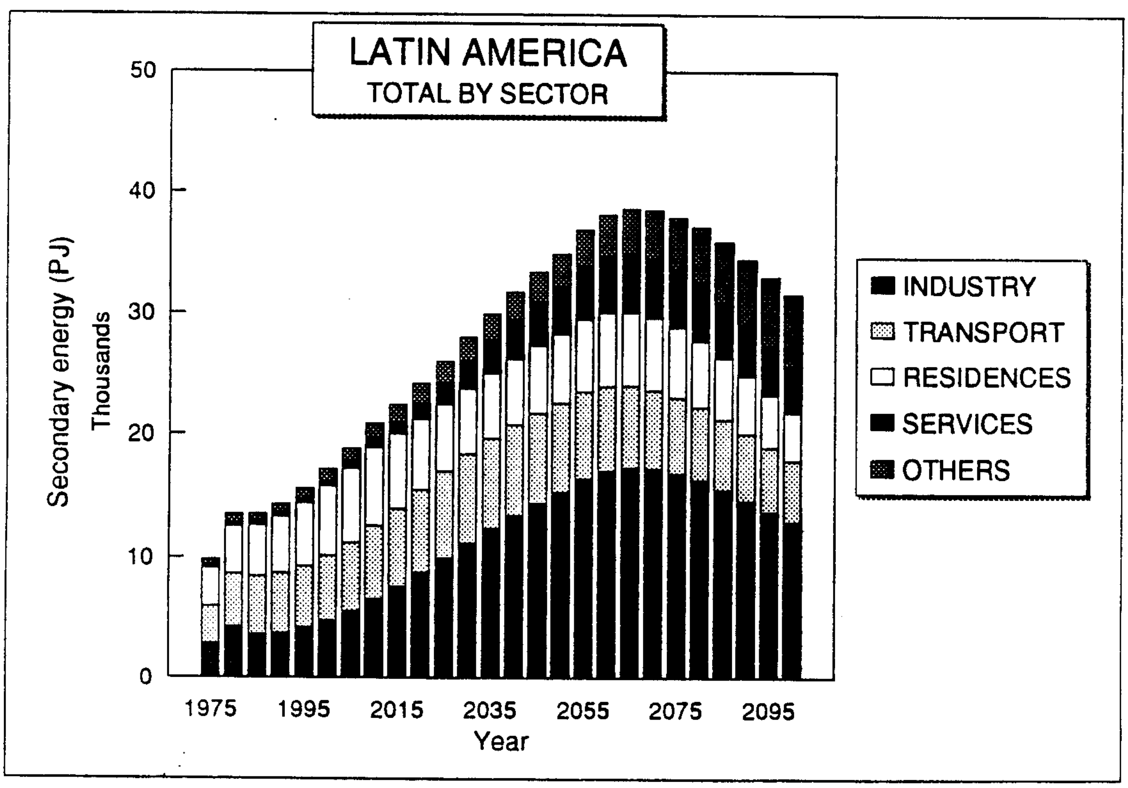


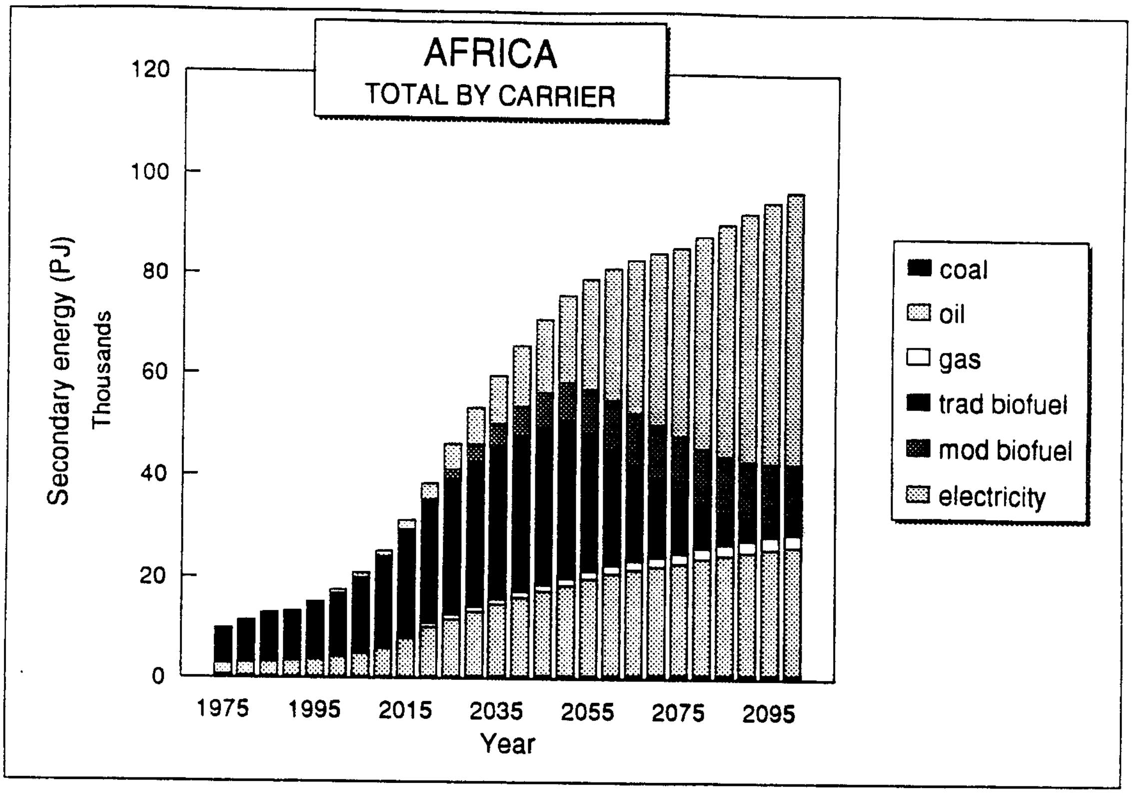


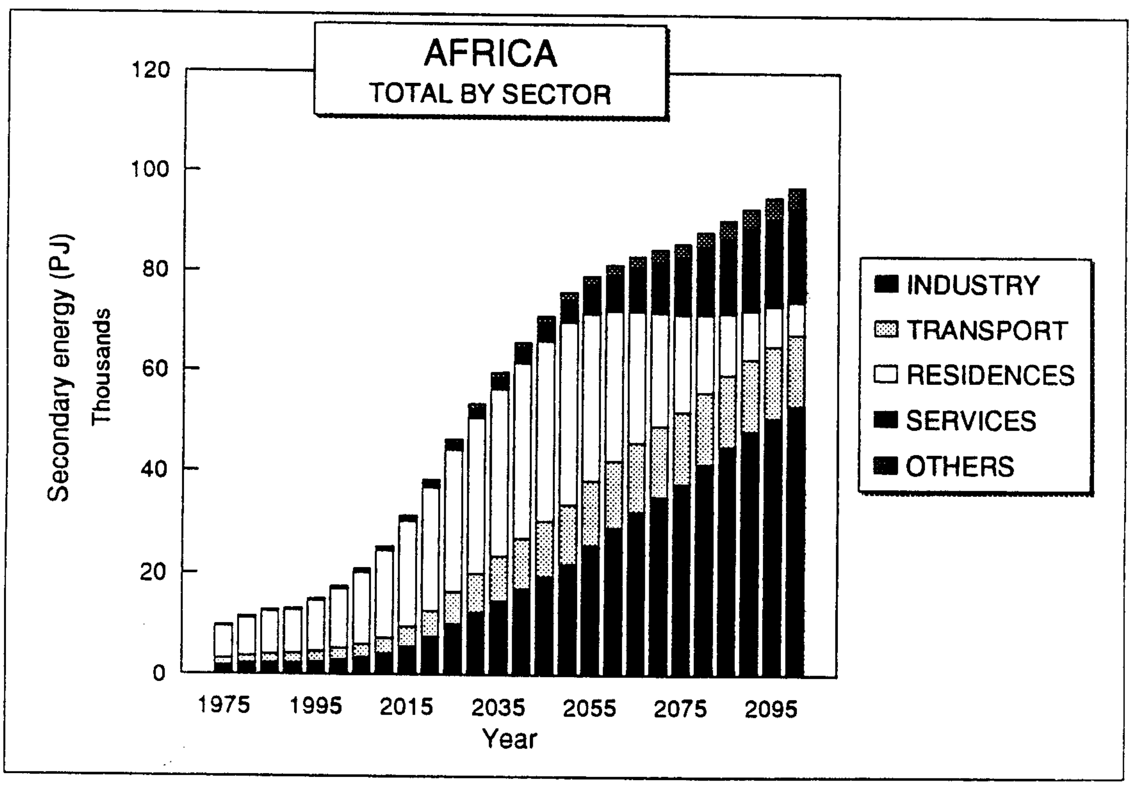

USA
TOTAL BY CARRIER
Secondary energy (PJ)
Thousands
60
40
20
0
1975
1995
2015
2035
2055
2075
2095
Year
coal
oil
gas
trad biofuel
mod biofuel
electricity

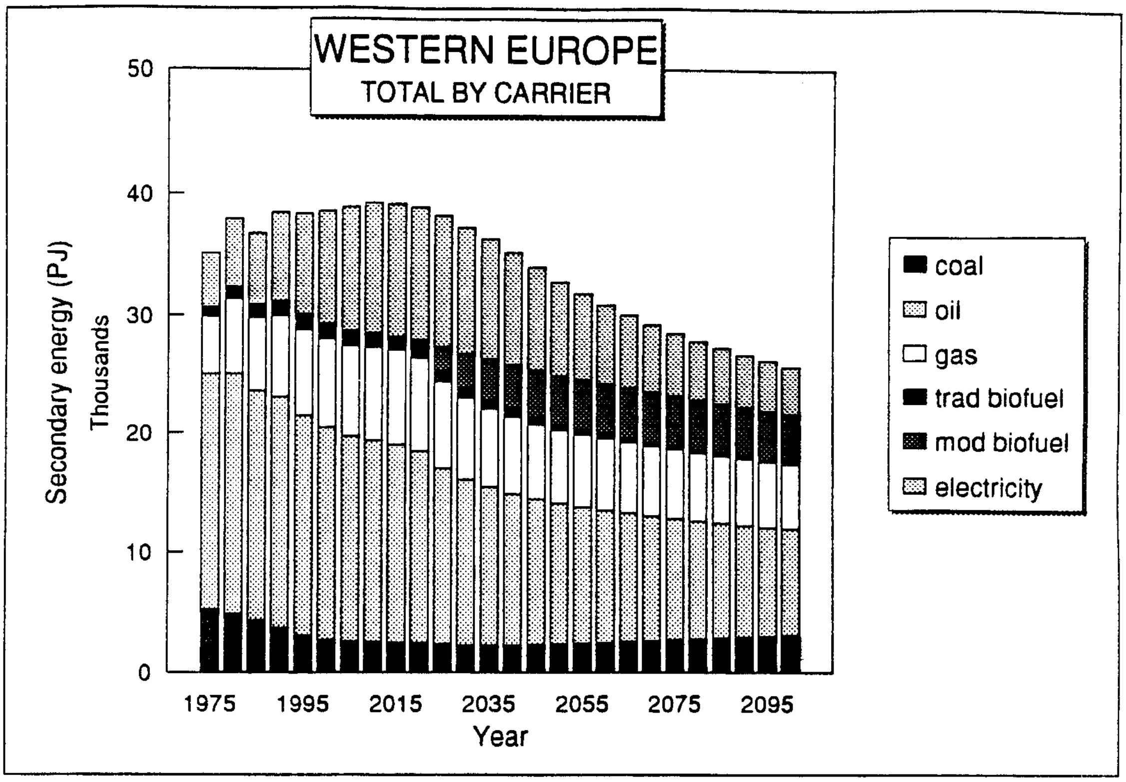

USA
TOTAL BY SECTOR
Secondary energy (PJ)
Thousands
60
40
20
0
1975
1995
2015
2035
2055
2075
2095
Year
INDUSTRY
TRANSPORT
RESIDENCES
SERVICES
OTHERS

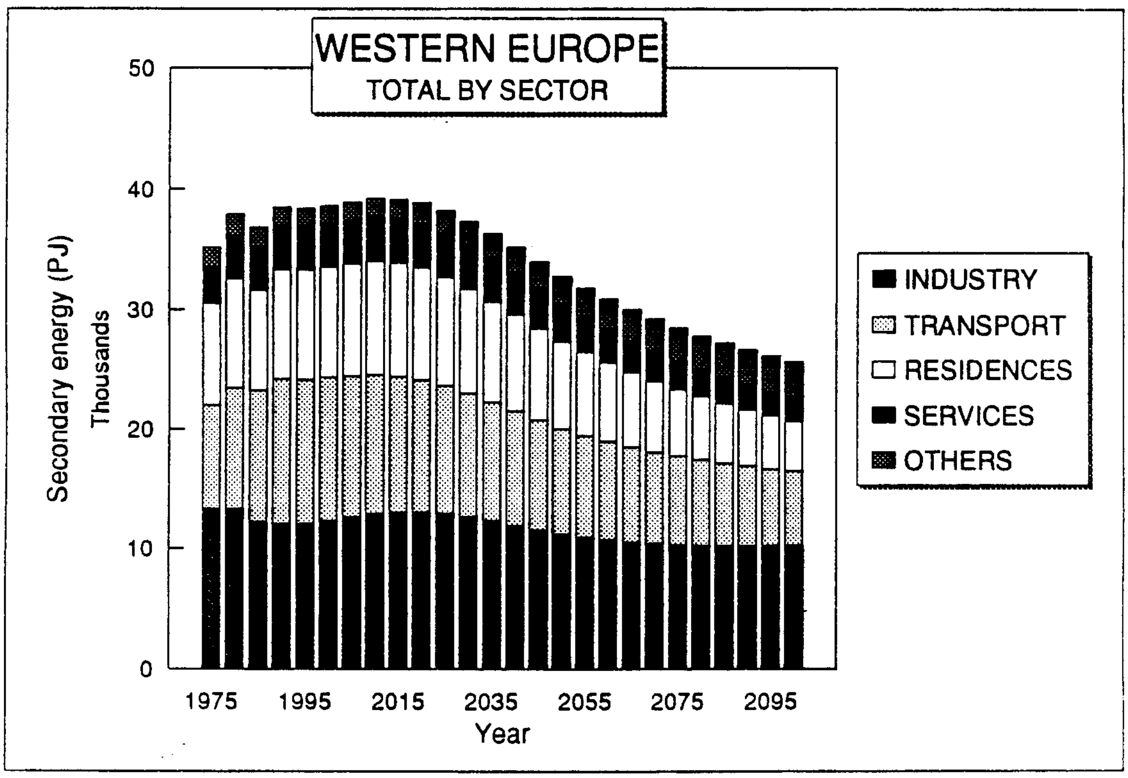

LATIN AMERICA
TOTAL BY CARRIER
Secondary energy (PJ)
Thousands
50
40
30
20
10
0
1975
1995
2015
2035
2055
2075
2095
Year
coal
oil
gas
trad biofuel
mod biofuel
electricity

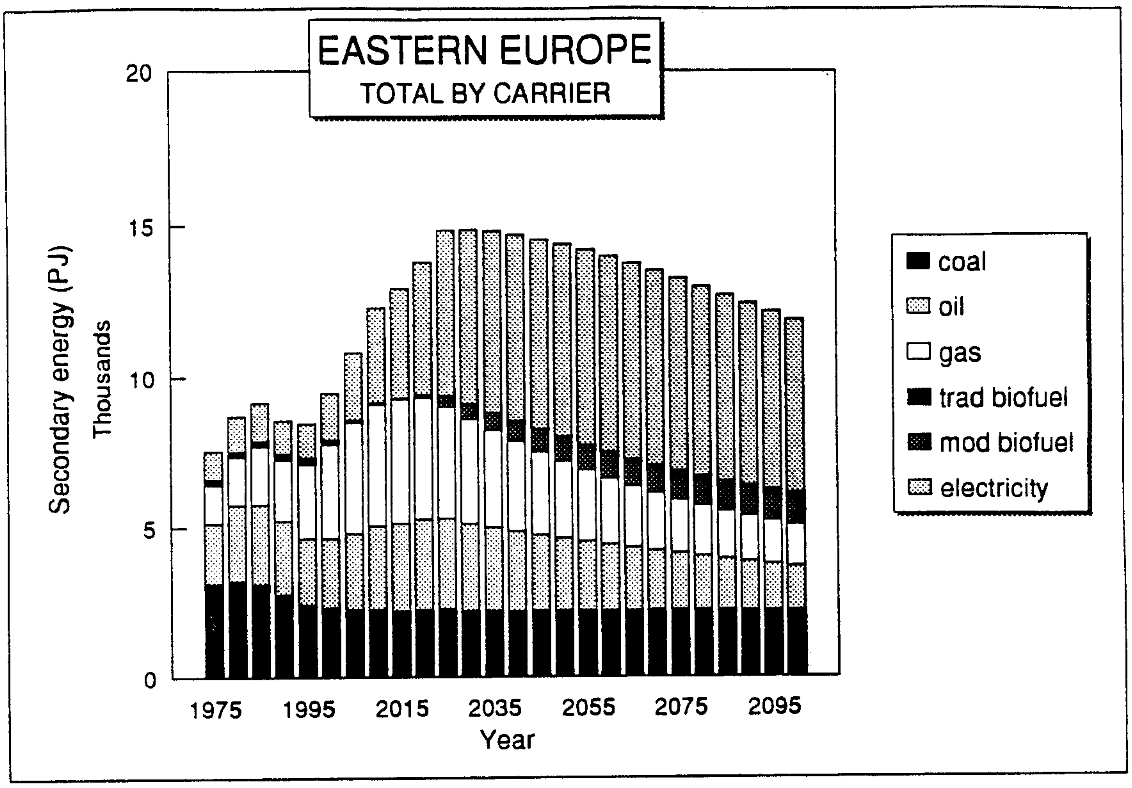

LATIN AMERICA
TOTAL BY SECTOR
Secondary energy (PJ)
Thousands
50
40
30
20
10
0
1975
1995
2015
2035
2055
2075
2095
Year
INDUSTRY
TRANSPORT
RESIDENCES
SERVICES
OTHERS

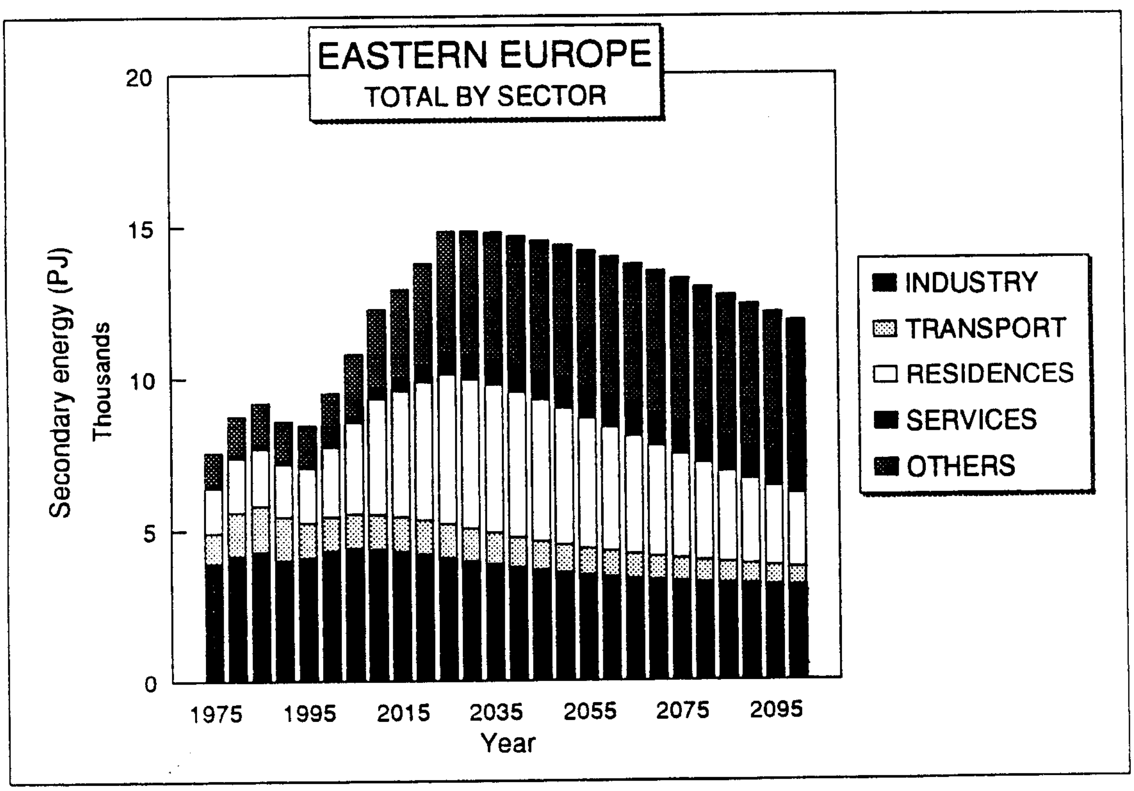

AFRICA
TOTAL BY CARRIER
Secondary energy (PJ)
Thousands
120
100
80
60
40
20
0
1975
1995
2015
2035
2055
2075
2095
Year
coal
oil
gas
trad biofuel
mod biofuel
electricity


AFRICA
TOTAL BY SECTOR
Secondary energy (PJ)
Thousands
120
100
80
60
40
20
0
1975
1995
2015
2035
2055
2075
2095
Year
INDUSTRY
TRANSPORT
RESIDENCES
SERVICES
OTHERS


WESTERN EUROPE
TOTAL BY CARRIER
Secondary energy (PJ)
Thousands
50
40
30
20
10
0
1975
1995
2015
2035
2055
2075
2095
Year
coal
oil
gas
trad biofuel
mod biofuel
electricity


WESTERN EUROPE
TOTAL BY SECTOR
Secondary energy (PJ)
Thousands
50
40
30
20
10
0
1975
1995
2015
2035
2055
2075
2095
Year
INDUSTRY
TRANSPORT
RESIDENCES
SERVICES
OTHERS


EASTERN EUROPE
TOTAL BY CARRIER
Secondary energy (PJ)
Thousands
20
15
10
5
0
1975
1995
2015
2035
2055
2075
2095
Year
coal
oil
gas
trad biofuel
mod biofuel
electricity


EASTERN EUROPE
TOTAL BY SECTOR
Secondary energy (PJ)
Thousands
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15
10
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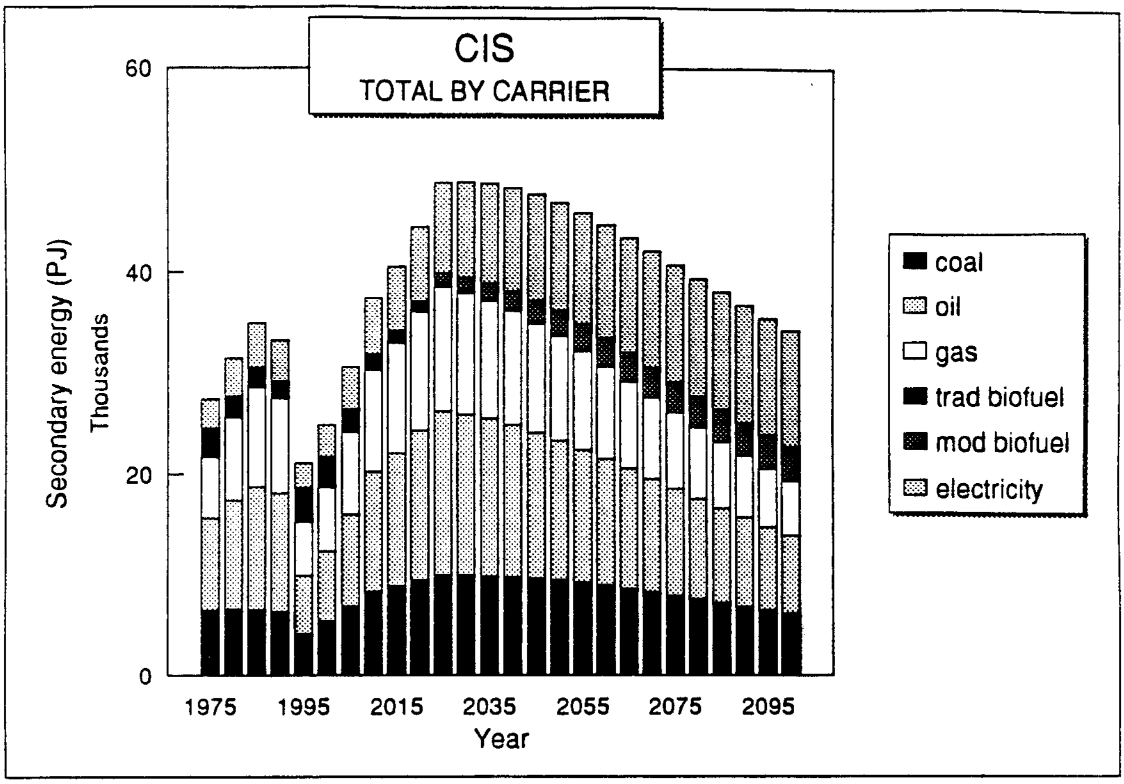
1995
2015
2035
2055
2075
2095
Year
INDUSTRY
TRANSPORT
RESIDENCES
SERVICES
OTHERS


CIS
TOTAL BY CARRIER
Secondary energy (PJ)
Thousands
60
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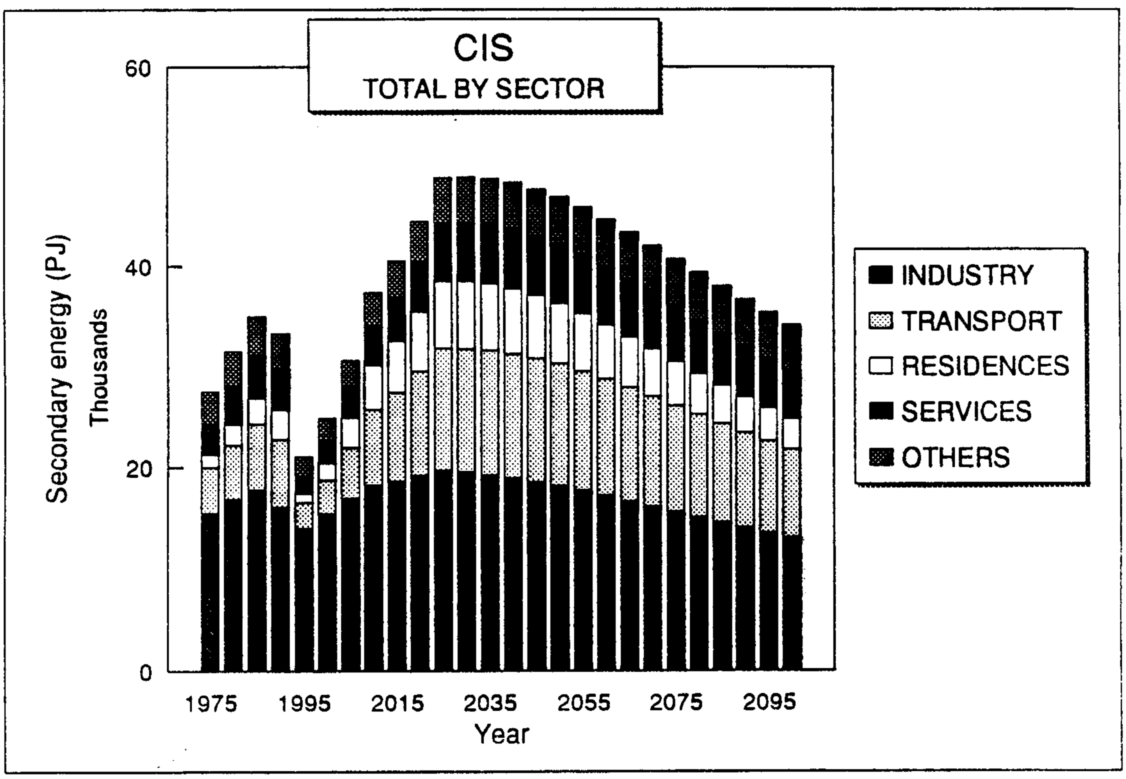
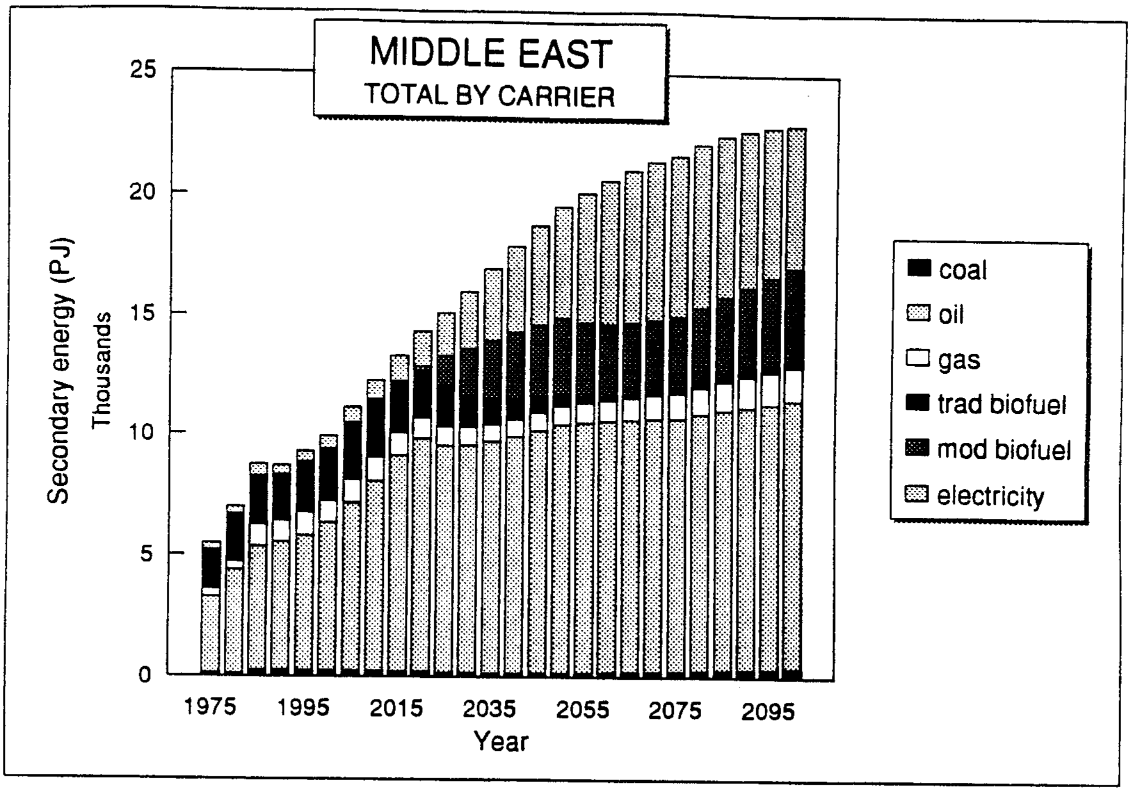
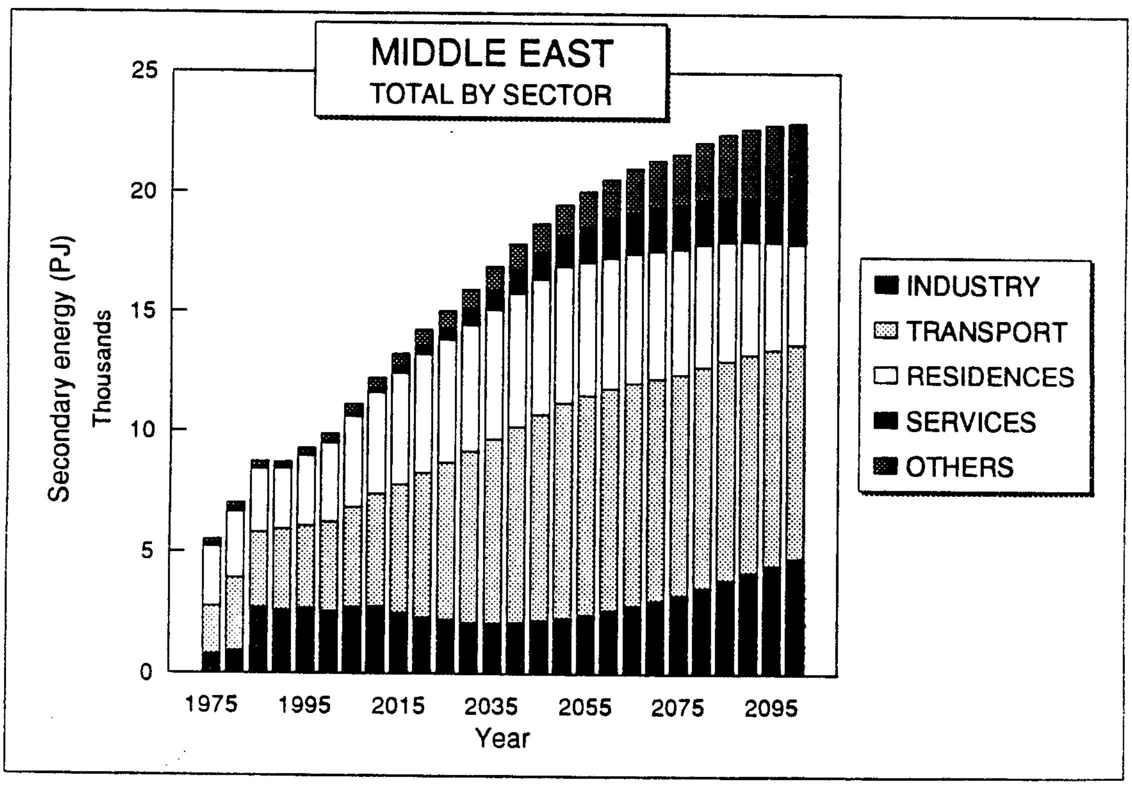
1975
1995
2015
2035
2055
2075
2095
Year
coal
oil
gas
trad biofuel
mod biofuel
electricity


CIS
TOTAL BY SECTOR
Secondary energy (PJ)
Thousands
60
40
20
0
1975
1995
2015
2035
2055
2075
2095
Year
INDUSTRY
TRANSPORT
RESIDENCES
SERVICES
OTHERS


MIDDLE EAST
TOTAL BY CARRIER
Secondary energy (PJ)
Thousands
0
5
10
15
20
25
1975
1995
2015
2035
2055
2075
2095
Year
coal
oil
gas
trad biofuel
mod biofuel
electricity


MIDDLE EAST
TOTAL BY SECTOR
Secondary energy (PJ)
Thousands
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5
10
15
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25
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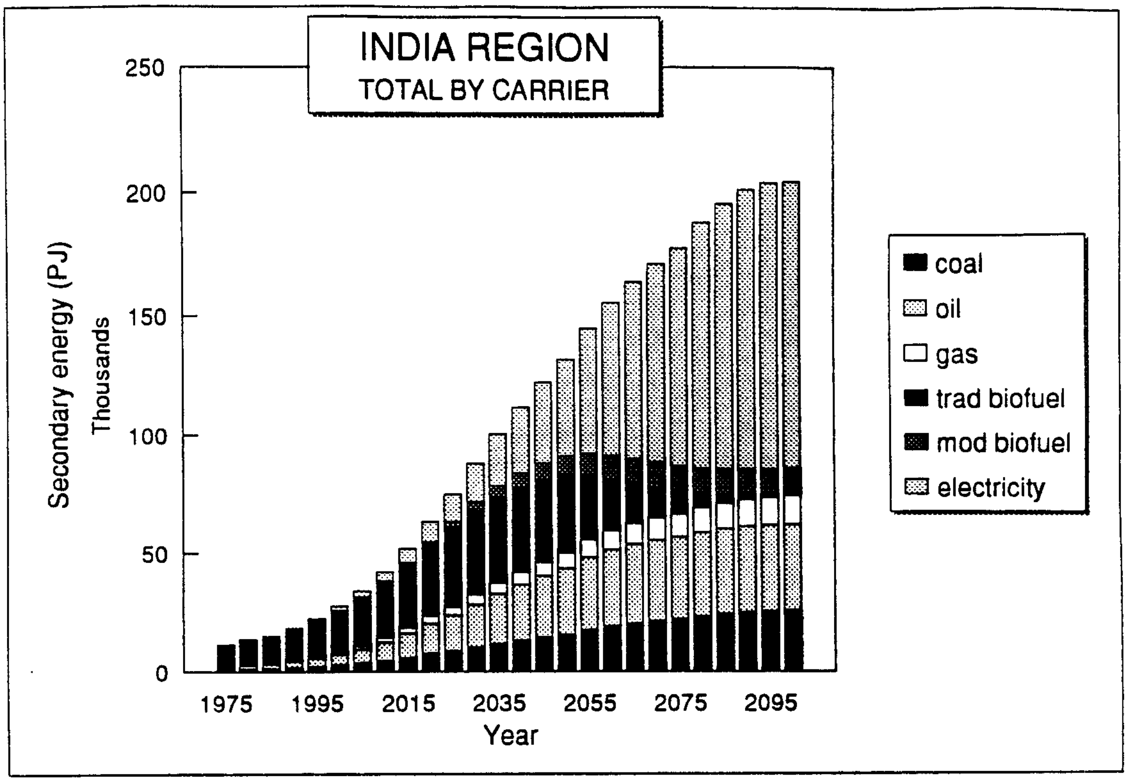
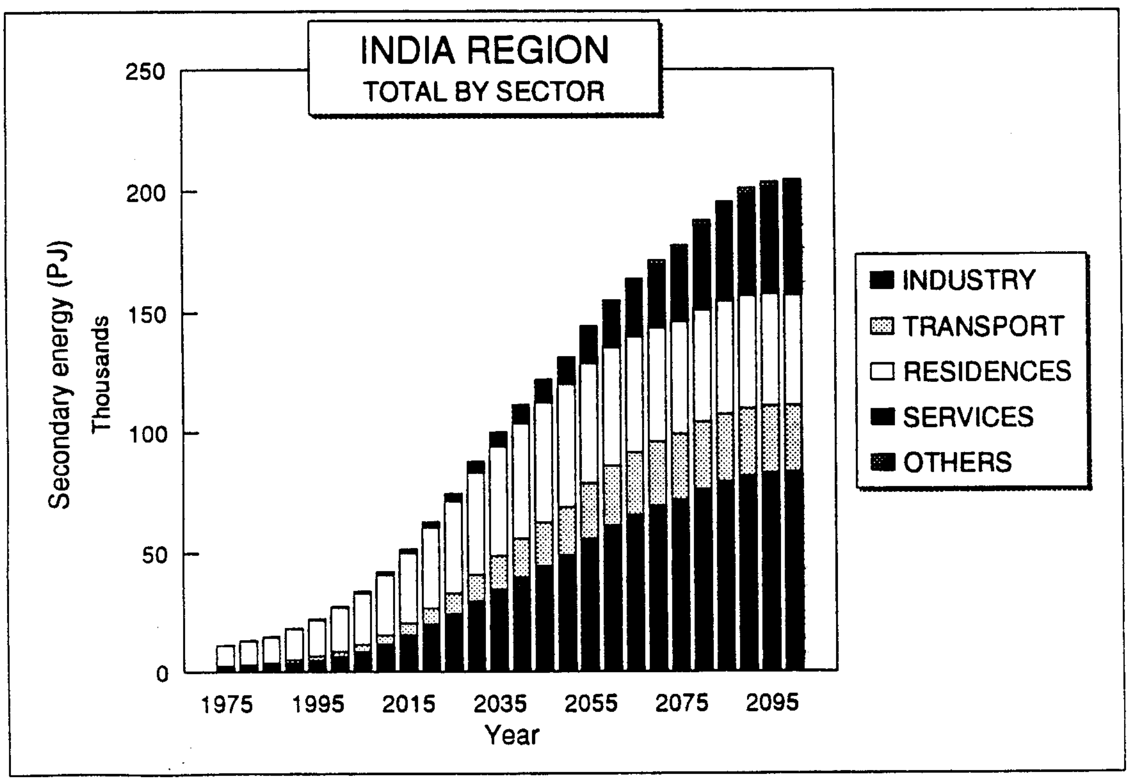
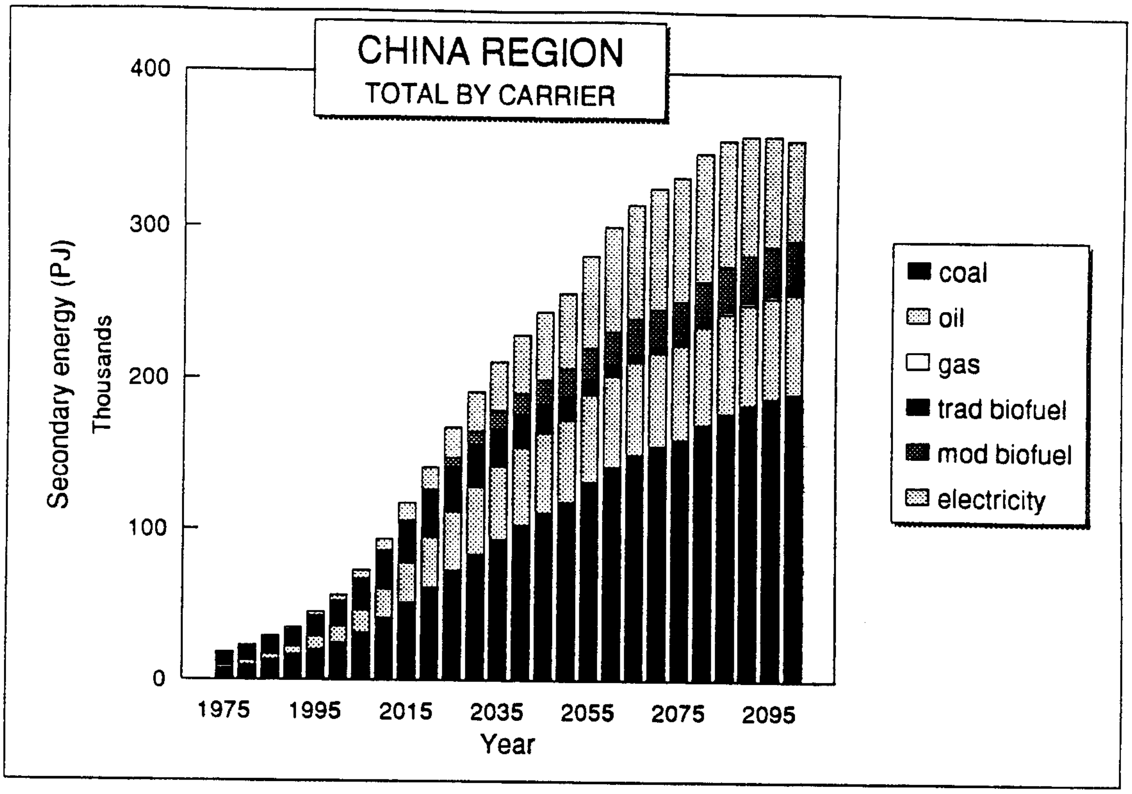
1995
2015
2035
2055
2075
2095
Year
INDUSTRY
TRANSPORT
RESIDENCES
SERVICES
OTHERS


INDIA REGION
TOTAL BY CARRIER
Secondary energy (PJ)
Thousands
250
200
150
100
50
0
1975
1995
2015
2035
2055
2075
2095
Year
coal
oil
gas
trad biofuel
mod biofuel
electricity


INDIA REGION
TOTAL BY SECTOR
Secondary energy (PJ)
Thousands
250
200
150
100
50
0
1975
1995
2015
2035
2055
2075
2095
Year
INDUSTRY
TRANSPORT
RESIDENCES
SERVICES
OTHERS


CHINA REGION
TOTAL BY CARRIER
Secondary energy (PJ)
Thousands
0
100
200
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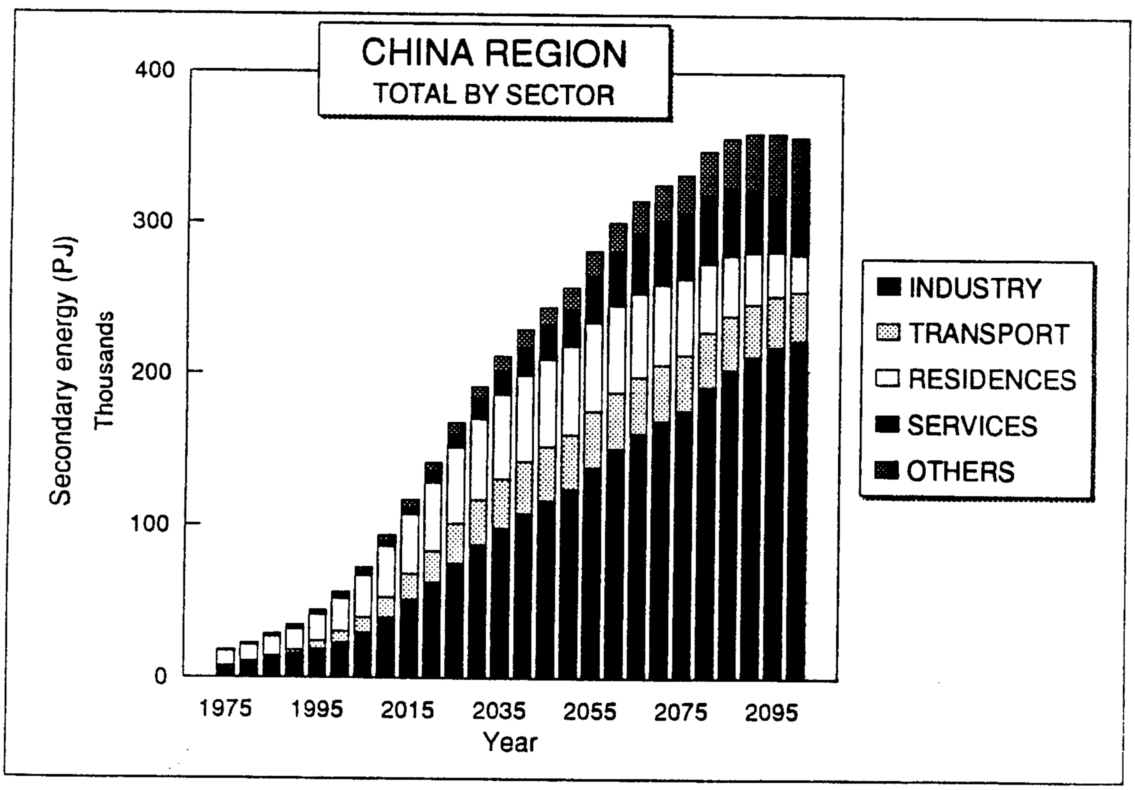
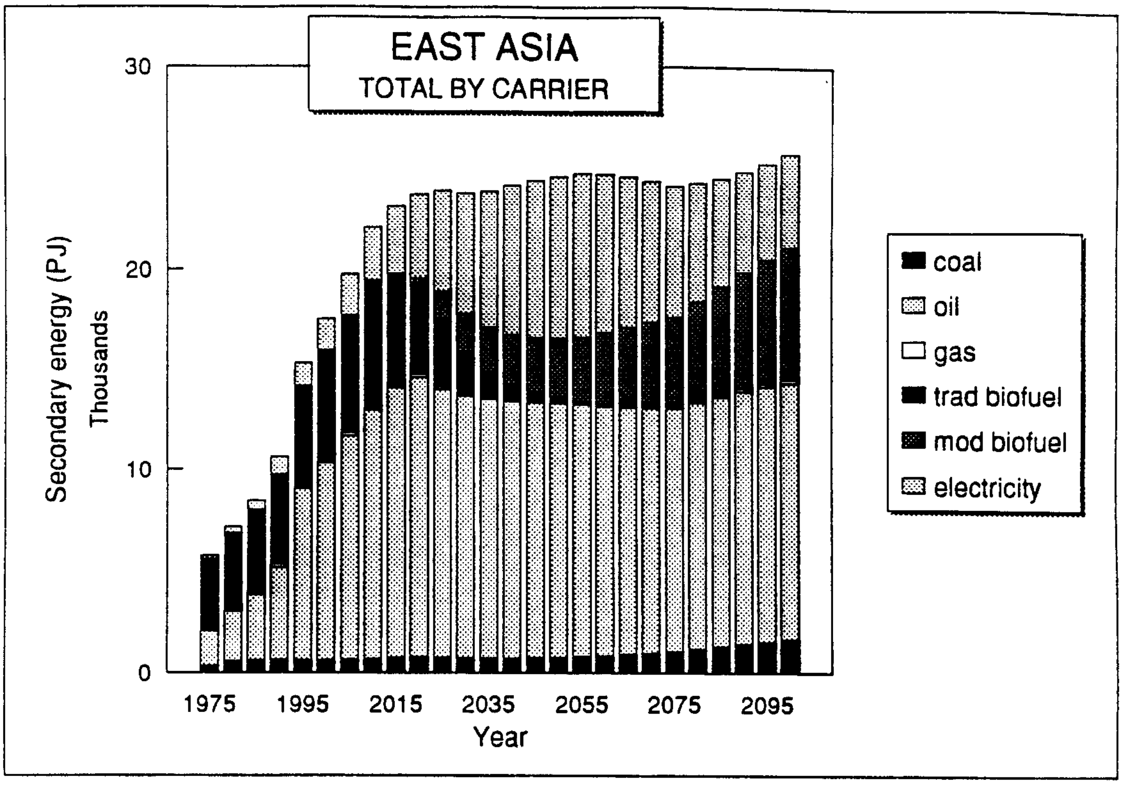
400
1975
1995
2015
2035
2055
2075
2095
Year
coal
oil
gas
trad biofuel
mod biofuel
electricity


CHINA REGION
TOTAL BY SECTOR
Secondary energy (PJ)
Thousands
0
100
200
300
400
1975
1995
2015
2035
2055
2075
2095
Year
INDUSTRY
TRANSPORT
RESIDENCES
SERVICES
OTHERS


EAST ASIA
TOTAL BY CARRIER
Secondary energy (PJ)
Thousands
30
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10
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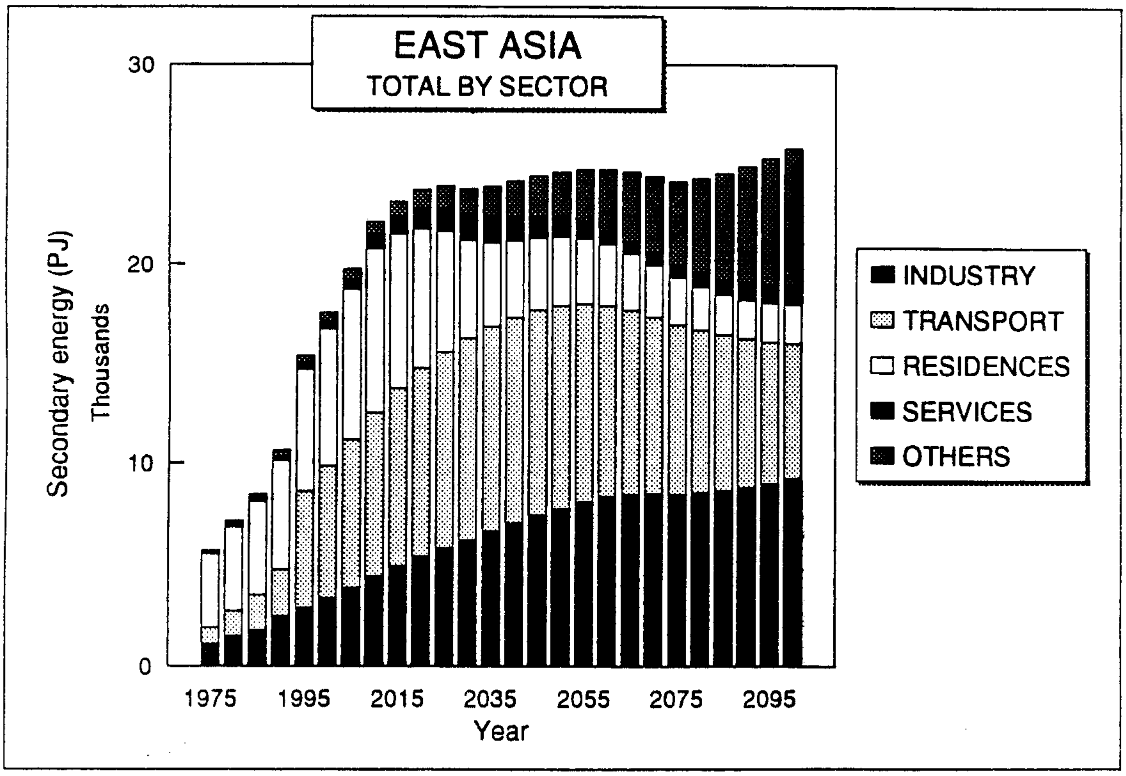
1975
1995
2015
2035
2055
2075
2095
Year
coal
oil
gas
trad biofuel
mod biofuel
electricity


EAST ASIA
TOTAL BY SECTOR
Secondary energy (PJ)
Thousands
30
20
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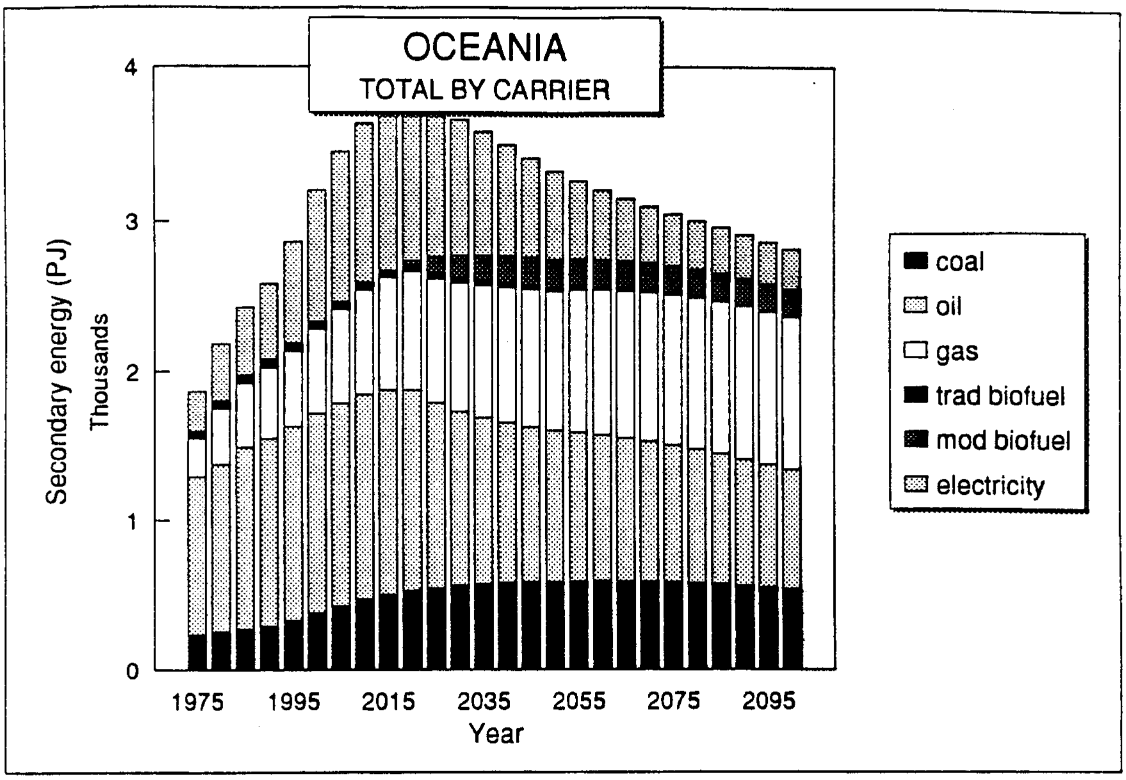
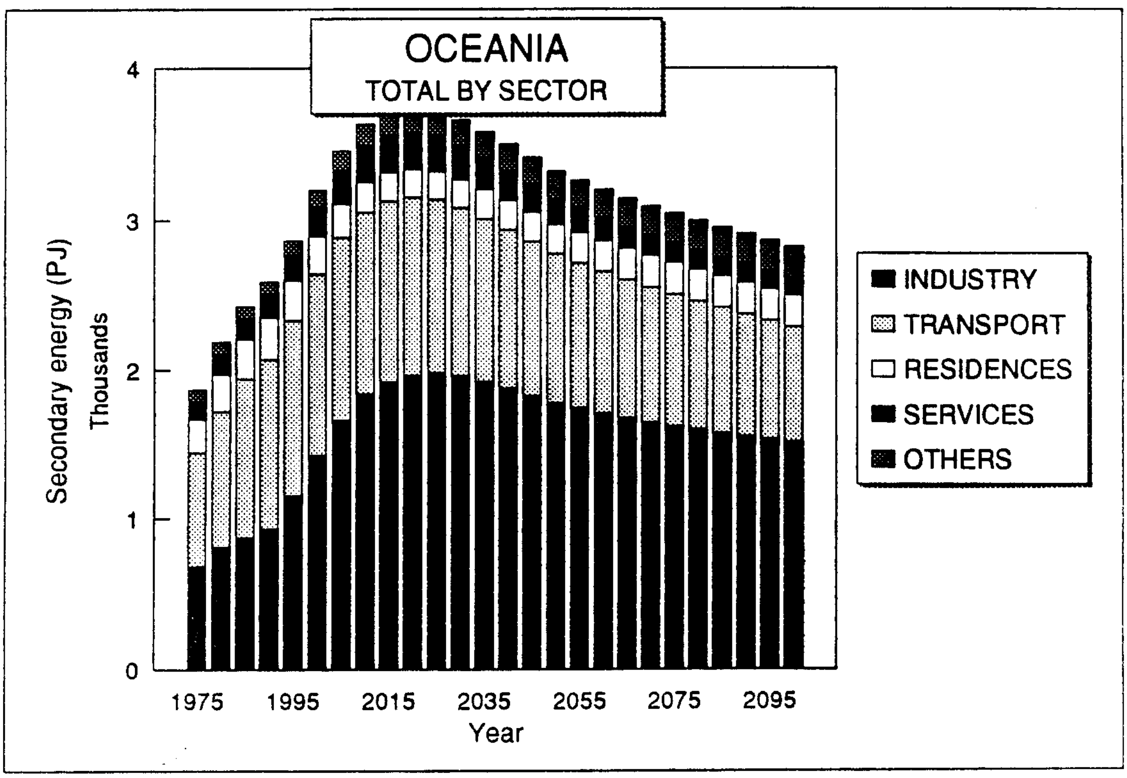
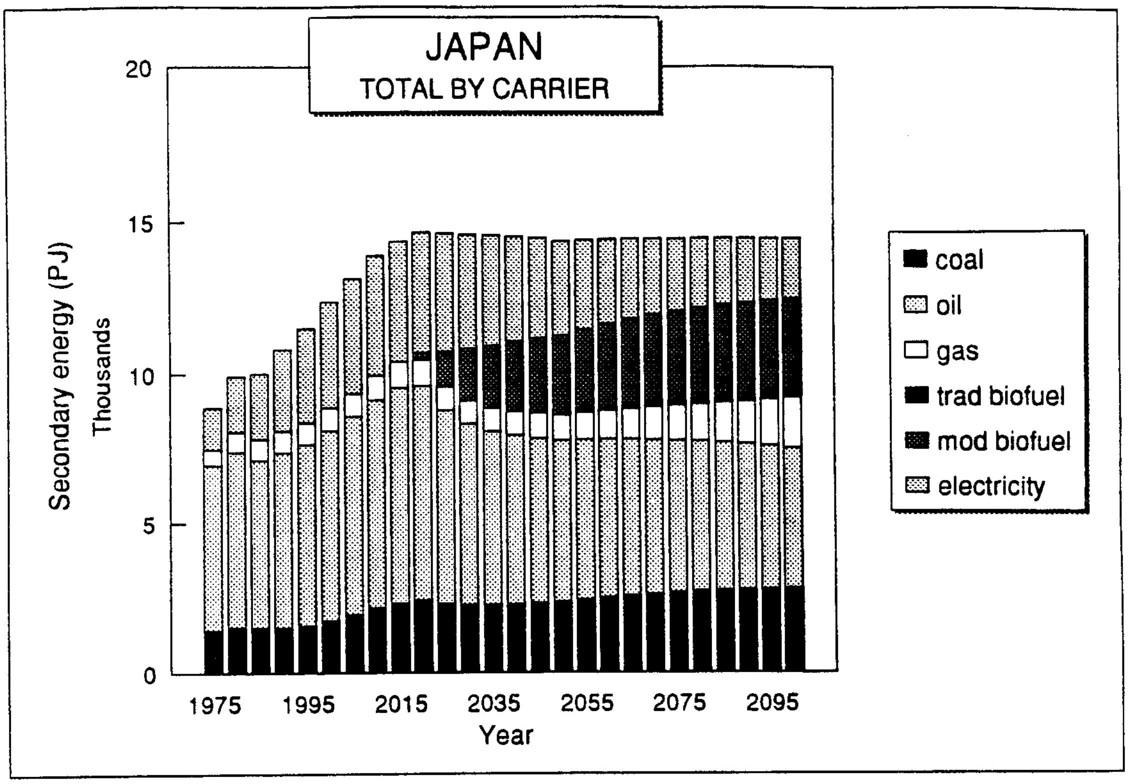
1995
2015
2035
2055
2075
2095
Year
INDUSTRY
TRANSPORT
RESIDENCES
SERVICES
OTHERS


OCEANIA
TOTAL BY CARRIER
Secondary energy (PJ)
Thousands
0
1
2
3
4
1975
1995
2015
2035
2055
2075
2095
Year
coal
oil
gas
trad biofuel
mod biofuel
electricity


OCEANIA
TOTAL BY SECTOR
Secondary energy (PJ)
Thousands
0
1
2
3
4
1975
1995
2015
2035
2055
2075
2095
Year
INDUSTRY
TRANSPORT
RESIDENCES
SERVICES
OTHERS


JAPAN
TOTAL BY CARRIER
Secondary energy (PJ)
Thousands
0
5
10
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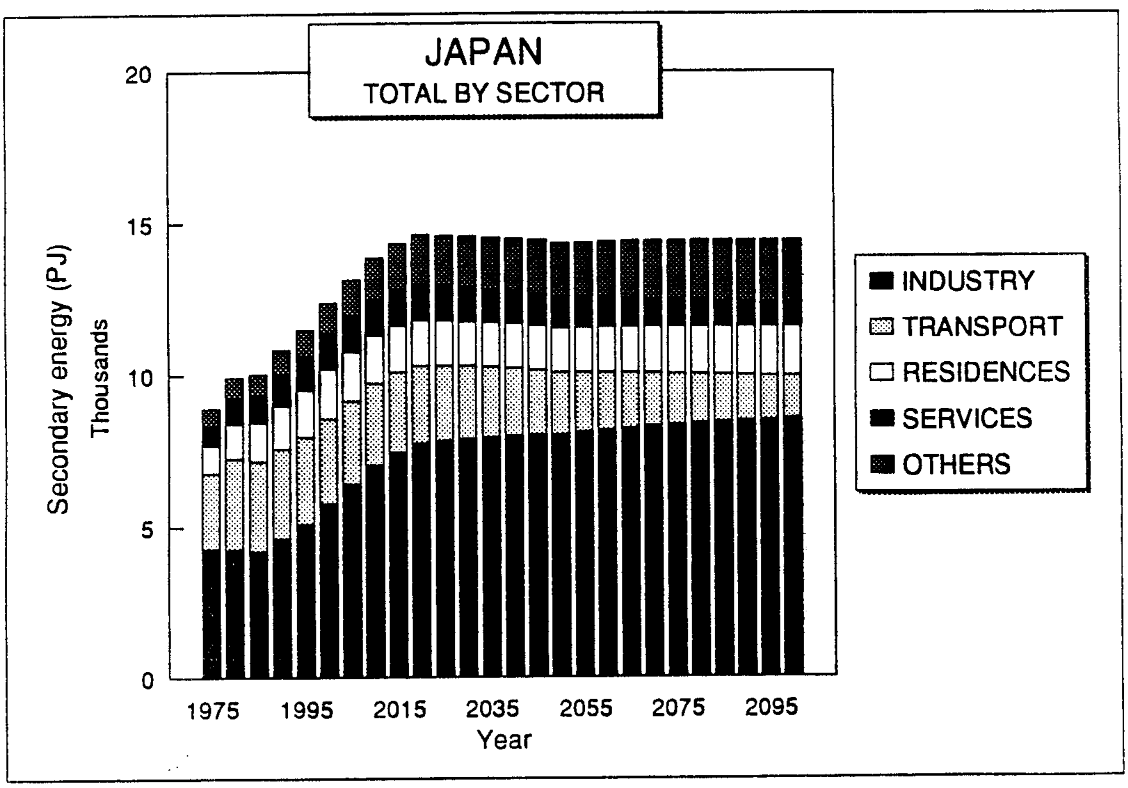
20
1975
1995
2015
2035
2055
2075
2095
Year
coal
oil
gas
trad biofuel
mod biofuel
electricity


JAPAN
TOTAL BY SECTOR
Secondary energy (PJ)
Thousands
0
5
10
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20
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1995
2015
2035
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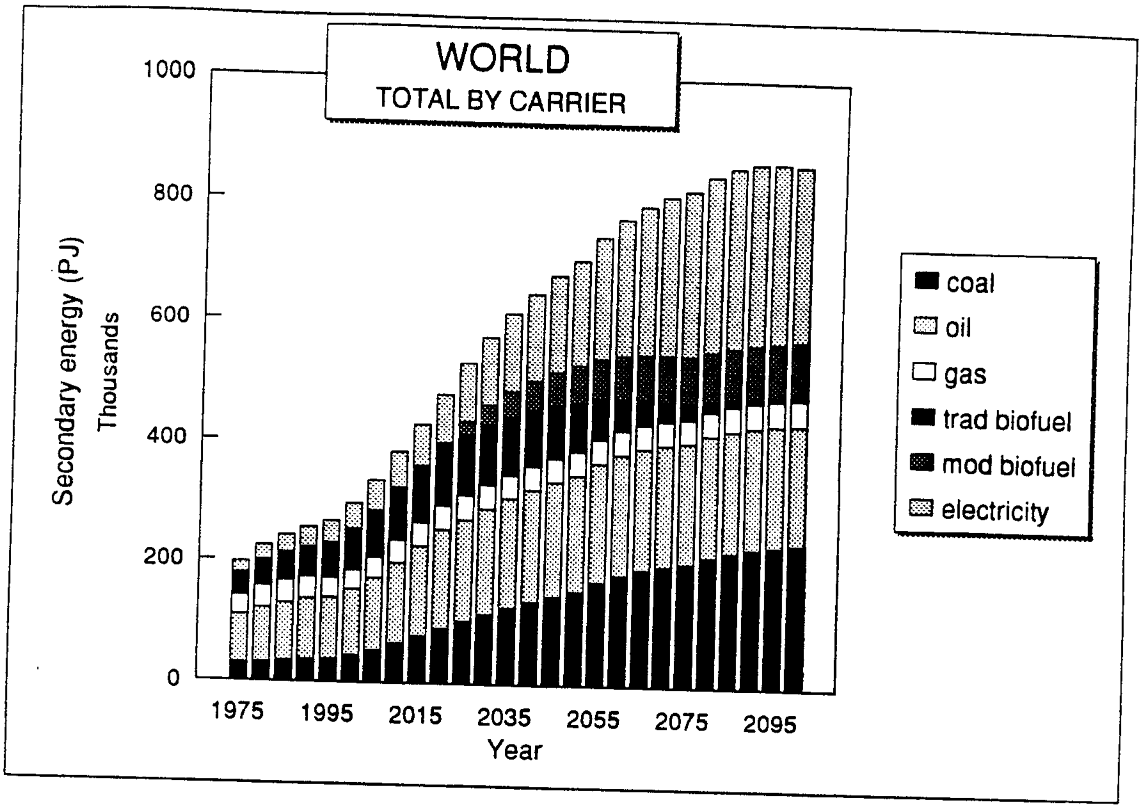
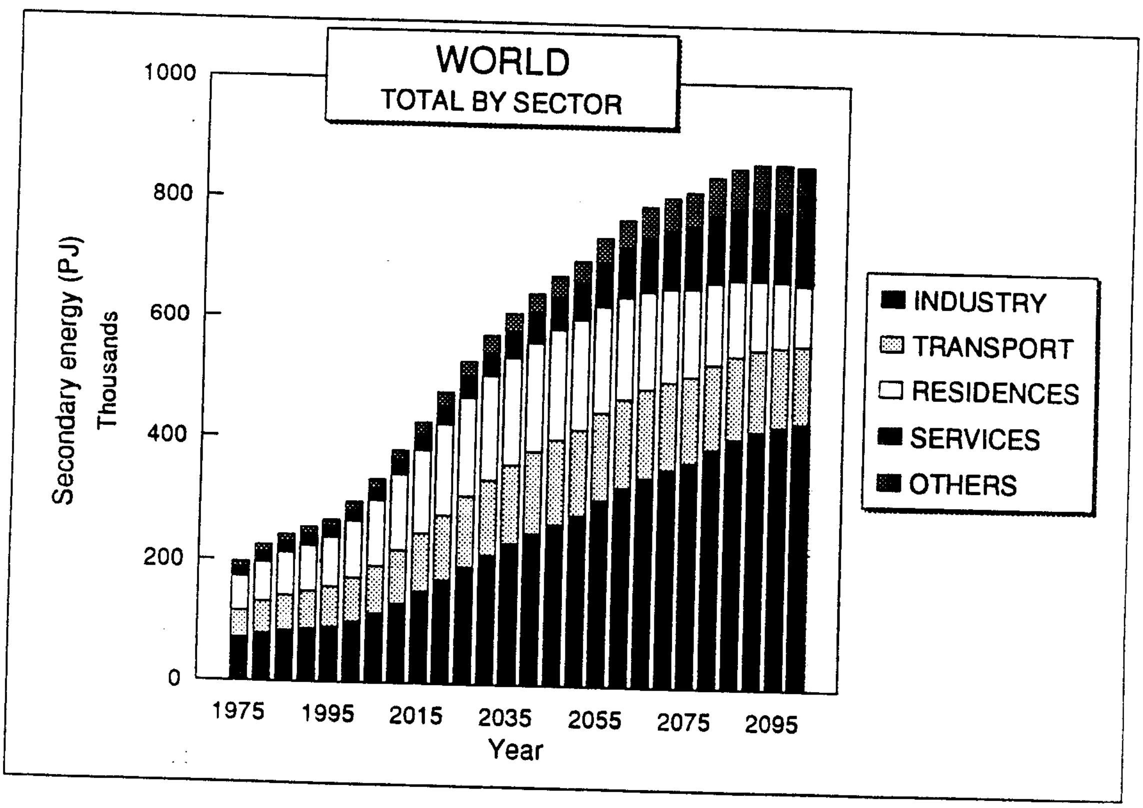
2075
2095
Year
INDUSTRY
TRANSPORT
RESIDENCES
SERVICES
OTHERS


WORLD
TOTAL BY CARRIER
Secondary energy (PJ)
Thousands
1000
800
600
400
200
0
1975
1995
2015
2035
2055
2075
2095
Year
coal
oil
gas
trad biofuel
mod biofuel
electricity


WORLD
TOTAL BY SECTOR
Secondary energy (PJ)
Thousands
1000
800
600
400
200
0
1975
1995
2015
2035
2055
2075
2095
Year
INDUSTRY
TRANSPORT
RESIDENCES
SERVICES
OTHERS