Modelling technological change and energy demand in economies in transition

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1. SYNOPSIS

A model is developed to investigate air pollution abatement policies in Eastern and Central Europe, with a focus on measures which effect energy demand.

2. ABSTRACT

The energy systems within Central and Eastern Europe are experiencing rapid change as countries move from centrally planned to market led economies. Patterns of energy use and supply will play key roles in determining the future level of air pollutant emissions. However, to date most studies have focused on alternatives for emission reduction in the energy supply sector only. Increased efficiency in energy use and fuel switches may offer opportunities for emission reduction at much lower cost, and it is essential that such options are compared objectively with those on the supply-side.

Under the prevailing conditions in Eastern Europe of rapid technological and structural change, conventional models based on econometric analysis or fuel price elasticities offer little insight into the process of reform. As such, it is difficult to assess the assumptions made and to gauge the accuracy of projections generated. An energy modelling approach based on the theories of technological innovation offers significant advantages for the investigation of the determinants of change.

A model is developed which takes explicit account of structural change whilst incorporating the major determinants of technological development. Policy intervention for emissions abatement through measures on the energy demand-side can be investigated through their effect on the uptake of efficient technologies and practices. There is great flexibility in the characterisation of energy end-use, facilitated by the use of an entity-relationship database design for the modelling package. The model is applied to analyse the changes in Hungary since the transition process began, and to investigate the likely path of future development.

3. INTRODUCTION

The countries of Central and Eastern Europe (CEE) are undergoing a process of radical reform, as they shift from centrally planned to market led economies. A major factor initiating this transition was public outcry over the scale of environmental. Within the region, local pollution has extremely adverse effects on human health, and transboundary pollution is a cause of concern for countries of Western Europe. Individual nations throughout Europe are already committed to a variety of national emission reduction targets, such as those agreed under the Second Protocol on Sulphur Dioxide, signed by many countries in June 1994 . However, the potential for more cost effective emission reduction in CEE than in Western Europe has aroused interest in the potential for emissions trading between countries.

Considerable attention is now focused on identifying the likely patterns of development for the economies of CEE. It is of great importance both for policy-makers within the region and without to understand the constraints that will limit social, economic and political change. The energy system is strongly affected by the transition and, in the short to medium term, may also prove to be one of the major constraints. Moreover, energy transformation and use are the major sources of air pollution. Analysis of the energy system, and consideration of the alternatives for development, is therefore of the utmost importance.

4. ENERGY DEMAND MODELLING FOR EASTERN EUROPE

4.1 The energy system in transition

Inappropriate resource allocation is largely responsible for the pollution problems faced by many countries of CEE. Incorrect pricing of resources and products is in part to blame. From very early in the transition process, many countries have been trying to liberalise prices, with the aim of re-allocation of resources through market pressure. Within the energy sector, this process of liberalisation has resulted in dramatic price increases for a number of energy products. However, some products are considered so important for reasons of social welfare, that the rate of price rise has been controlled. As a result, prices for natural gas and electricity to domestic customers are generally still well below those found in Western Europe, and below the full cost of supply (IEA 1994).

Nonetheless, fuel price rises have had a strong effect on demand, with evidence of both demand reduction and inter-fuel switching, as will be discussed in the case study of Hungary later. The magnitude of the rises makes analysis by conventional econometric methods inappropriate. Consumer response to further price increases in the future is therefore difficult to predict.

The pattern of energy end-use has also been altered by significant non-price effects. The industrial sector is the major consumer of energy in most countries of CEE. With the collapse of central planning, trade agreements between the COMECON countries began to disintegrate, and many branches of industry suffered decline. National recession resulted in a drop in domestic consumption, and general world recession made western export markets hard to develop. Despite gradual economic recovery since 1993, much of the industry which has closed is not expected to re-open. Markets have changed permanently, and new pressures from higher resource cost will ensure considerable change in industry shares as recovery continues (Hungarian Ministry of Industry and Trade 1993). Such radical structural change has implications for energy-use, and consequently for pollution emissions. Many of the industries which have declined most rapidly are energy-intensive, and energy price rises may ensure that such industry never recovers.

Energy-use in the non-productive sectors is also changing rapidly. With the lifting of many import restrictions, the range and availability of consumer durables has grown rapidly. Whilst the anticipated rush to purchase western luxuries has been tempered by recession, spending patterns are certainly changing. These changes cannot be explained solely in terms of income and price effects, since the pre-transition ownership levels were limited by many other factors. Future ownership patterns are at present hard to predict.

The previous discussion has demonstrated the large scale of the structural changes expected in the energy sector as the transition continues. However, the discussion also highlights the great uncertainty which surrounds the precise nature and timing of the changes. Despite the obvious difficulty in forecasting the exact changes expected under these conditions, it is essential to achieve a level of understanding of the process. Finance within the CEE region is scarce, and it is important to ensure that the finance available is directed to the areas in which most benefit may be achieved. Within the field of energy-related pollution abatement, this task involves finding the correct distribution of support between activities for improving energy supply and for improving energy use. Considerable effort has already been expended in assessing the costs and benefits of alternative strategies for achieving emission reductions. These activities have largely focused on alternatives for investment in the various energy supply industries (for example, the work at the International Institute for Applied Systems Analysis using the RAINS model, and studies undertaken by the Institute of Industrial Production at Karlsruhe using EFOM-ENV). Such alternatives may be more easily assessed and compared than relatively heterogeneous options involving energy demand. However, from pilot programmes and other research efforts (for example, demonstration zones funded by the United Nations-Economic Commission for Europe program Energy Efficiency 2000), it is clear that options on the demand side may offer great potential for cost-effective emission abatement, with numerous other secondary benefits. Analysis of the alternatives for emission abatement from the energy-using sectors of CEE is therefore a priority, and a suitable approach for modelling the rapidly changing system needs to be identified.

4.2 Development of energy demand modelling methodologies

Before the oil crises of the early 1970's, most studies of the energy sector were concerned with estimation of demand through simple econometric models, and optimisation of supply to meet demand. These simple econometric models usually relied on the use of income and price elasticities alone. Following the oil crises, it quickly became apparent that such models were inadequate, as they were incapable of responding to effects on the energy sub-system of basic changes in the economic system. In particular, the reaction to price shocks and non-price related policy measures could not be represented in the early models (Lapillone et al 1991)

In response to concerns about past reliance on econometric approaches for forecasting, a new generation of techno-economic models were developed. Analysis was focused on the long-term effects on energy demand of energy price changes and energy conservation activities. The early examples of such models can best be described as accounting frameworks, involving the exogenous derivation of scenarios for socio-economic and technological change. This approach has proved both popular and useful. Many of the determinants of demand are made explicit, and the models yield simple answers for the long term development of energy resources (Reddy 1991). However, price effects cannot be included explicitly within such models, and the data requirements are arduous.

During the 1980's, the trend was for a convergence of the econometric and techno-economic approaches for demand estimation. Econometric models incorporating technical and economic factors and techno-economic models including price effects on inter-carrier substitution and end-use share were developed. The development of such hybrid modelling approaches was partly driven by a rise in interest of application of energy modelling to different regions of the world, most notably in developing countries. Features of both econometrics or simple techno-economic models rendered them unsuitable for direct application in regions where markets were severely distorted and data not comprehensive.

The particular features of the economies of CEE as they make the transition to market-led structures makes analysis with existing general modelling tools cumbersome and often uninformative. Markets are still very distorted, energy prices do not reflect average or marginal costs, structural change is rapid and consumer decisions are influenced to a great degree by non price-related factors. The work described in this paper concerns the construction of a modelling tool which is better suited to the particular purpose.

4.3 Specification of the required modelling tool

Table 1 summarises the particular characteristics of CEE which affect the design of an appropriate energy demand modelling tool. The second column of the table outlines the response to each characteristic which is adopted in this work.

Table 1. Characteristics of modelling tool

Characteristic of CEE	Modelling approach
Available data not comprehensive	Flexibility in specification of sector structure, energy services, technology characteristics and energy carriers
Markets distorted, price responses uncertain	Avoid elasticity approach for general development of demand Use prices for investigation of specific policy measures
Rapid structural shifts (both discrete jumps and continuous change)	Specify structure explicitly every modelling period

Rapid technological innovation and change in appliance ownership	Explicit consideration of technological substitution
Uncertainty in structural shifts and technology diffusion	Scenario approach Modular data-sets

Two features of the approach are of particular importance, and will be described in greater detail: firstly, the implementation of explicit technology substitution and secondly the use of a modular approach to facilitate flexibility in the choice of data types.

4.3.1 *Technological substitution*

Changes in the way energy is used comprise of changes in energy-using activities, changes in building fabric and changes in the stock of end-use equipment. All of these changes can be represented by the diffusion of a new activity or technology in substitution for an existing one. Empirical work on the diffusion of innovation shows that markets develop according to an S-shaped curve (for example, see Stoneman 1988). There is slow diffusion at first, when information and experience is limited. Maximum diffusion rates are limited by factors such as availability of equipment and investment finance. Finally, the rate of penetration slows as the market approaches saturation. This diffusion profile can be described by the Sigmoidal family of curves, which represent the cumulative density curves derived from bell-shaped frequency distributions. The most commonly cited form of the Sigmoidal curve is the logistic.

The logistic curve is defined by two parameters: a measure of diffusion speed and a measure of the final level of diffusion, known as the saturation level. Diffusion speed is most easily represented by the time taken (t^*) for the level of diffusion (n_t) to reach half of the final saturation level (n_{sat}).

$$\textit{At half of final saturation,}\quad n_t \ \frac{n_{sat}}{2} \qquad (1)$$

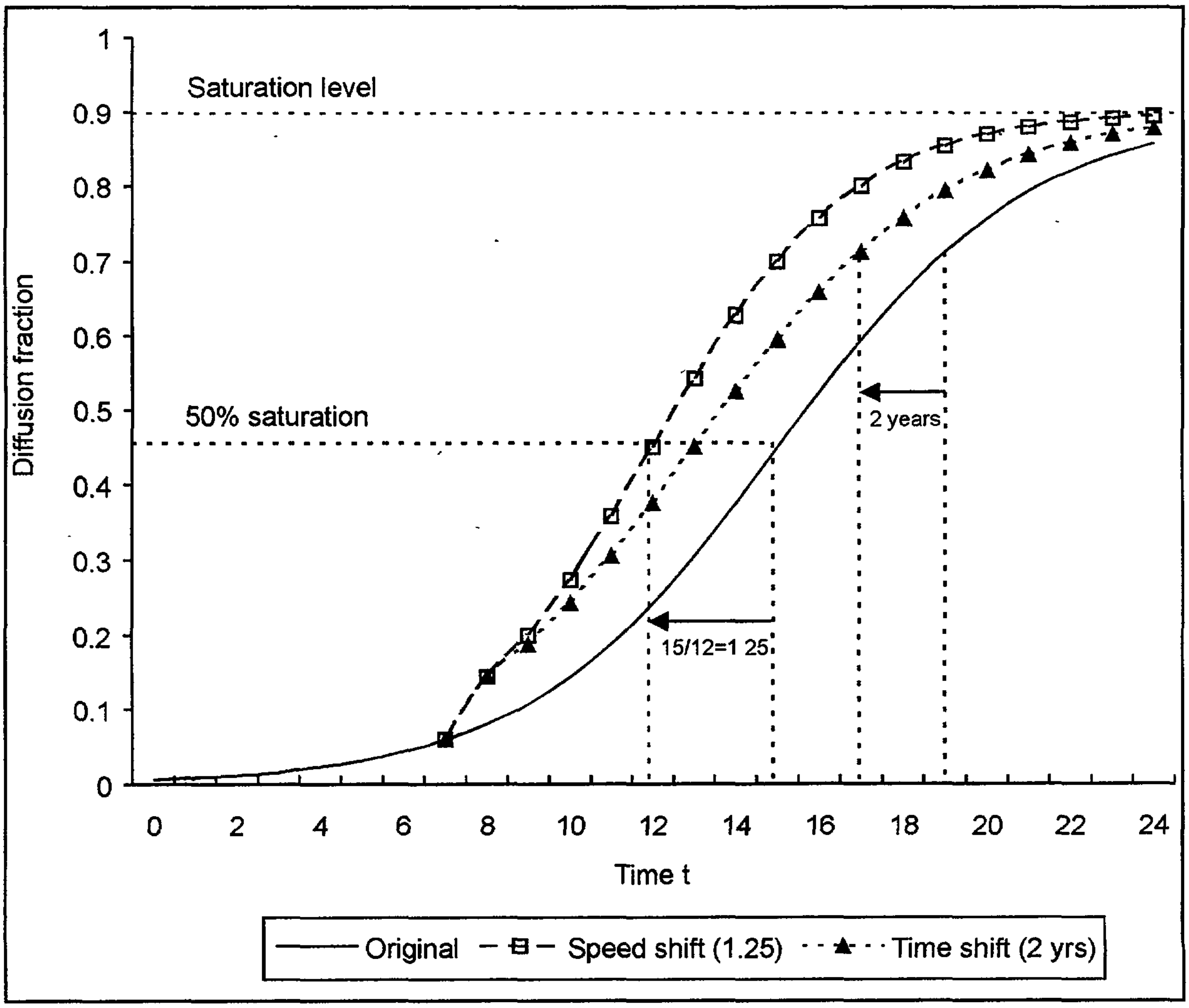
$$\textit{For logistic curve,}\quad n_t \ \frac{n_{sat}}{1\ e^{\ a\ bt}} \qquad (2)$$

$$\textit{Substituting (1) into (2), gives}\quad t \ \ \frac{a}{b} \qquad (3)$$

Adjustment of the generic sigmoid curve to fit the penetration profile expected for a particular technology or sector is achieved through manipulation of the logistic function. Changing the value of `a' shifts the curve along the time axis, and `a' may thus be set to achieve the desired level of penetration existing at time t = 0. The variable `b' may then be used to alter the slope of the curve, and hence the time taken to reach fifty percent saturation. Saturation level in the model is set individually for each technology and sector, and should encompass all firms or households that are physically capable of adopting the new technology.

The time to reach fifty percent of the saturation level is determined by fundamental features of both the technology considered, and the market into which it is diffusing. Empirical studies have identified the most important of these features as profitability of the investment and the risk attached. The precise measure of each of these features that performs best varies considerably between different studies (Ray 1984). In an attempt at simplicity, profitability is represented here by the simple payback period and risk by investment as a proportion of annual budget. The general demand response of residential and industrial consumers to changes in these parameters has been estimated through analysis of results reported for particular technologies in the literature (for example, studies of the uptake of various conservation measures in the residential sector reported in DoE and DoT 1981). The model allows for manual adjustment of the diffusion curves which are generated by this process, to allow the representation of market distortions and other effects.

Policies aimed specifically at changing technology adoption rates can be represented by further modification to the curve for any individual or set of technologies. Policies which involve dissemination of information are assumed to stimulate increased adoption of the technology in a particular period. This effect is represented by a shift of the whole diffusion curve towards the time-axis origin. Where the dissemination of information about a new technology is not a limiting factor, a change in the perceived attractiveness of the technology, whether through a tax incentive or other measure, will affect all potential users simultaneously. The effect of such a measure is to "step" the diffusion onto a steeper or faster curve. Figure 1 shows an example of a diffusion curve, together with modifications of both types made in year seven. The example shows the effect of an information campaign which brings diffusion forward by two years, and of a policy which increases the speed of diffusion by a factor of 1.25.



4.3.2 *Modular construction*

The lack of consistent data for energy service requirements, technology characteristics and end-use structure hampers the construction of traditional techno-economic models. Such models frequently require data entry into standardised forms, with little choice of units or calculation basis. The present model is constructed as a looser framework, which requires only that the final result of the interaction of technology with end-use with energy service be a figure for delivered energy demand. Into this framework may be inserted any representation of energy service demand and technologies or processes to fulfil that demand.

The implementation of such a framework is facilitated through the use of a Database Management System approach. Characteristics of technologies, services and sector structure are stored in individual tables from which the desired items may be freely selected. The nature of each characteristic can be chosen to suit the available data, and explanatory memo items can be stored with each.

The database has been designed to fulfil the criteria of modularity, with distinct sets of information maintained in individual units. Alternative scenarios may then be constructed by combining different versions of each data set type. The model is managed through a system of graphical screens and pull-down menus, developed alongside the programs which manipulate the database. The screens facilitate data editing, database interrogation and the output of results in tabular and graphical form.

5. APPLICATION OF MODEL FOR EMISSIONS ABATEMENT IN HUNGARY

The model is presently being used to analyse the energy demand system in Hungary, and to investigate alternative scenarios for the future.

For the period 1989 to 1993, the model has been used primarily as a accounting framework, to simulate the actual reported development of energy end-use in Hungary. Extensive use has been made of data from the Central Statistical Office in Budapest (for example, HCSO 1993), and of energy statistics published by the State Authority for Energy and Energy Safety (State Authority for Energy and Energy Safety 1993). For 1994 to 2010, the capacity of the model to simulate changes in technological development in a flexible manner, incorporating the effect of fuel price development and non price-related factors is used.

This work is not yet complete, and in this paper is presented just an example of the analysis that may be undertaken.

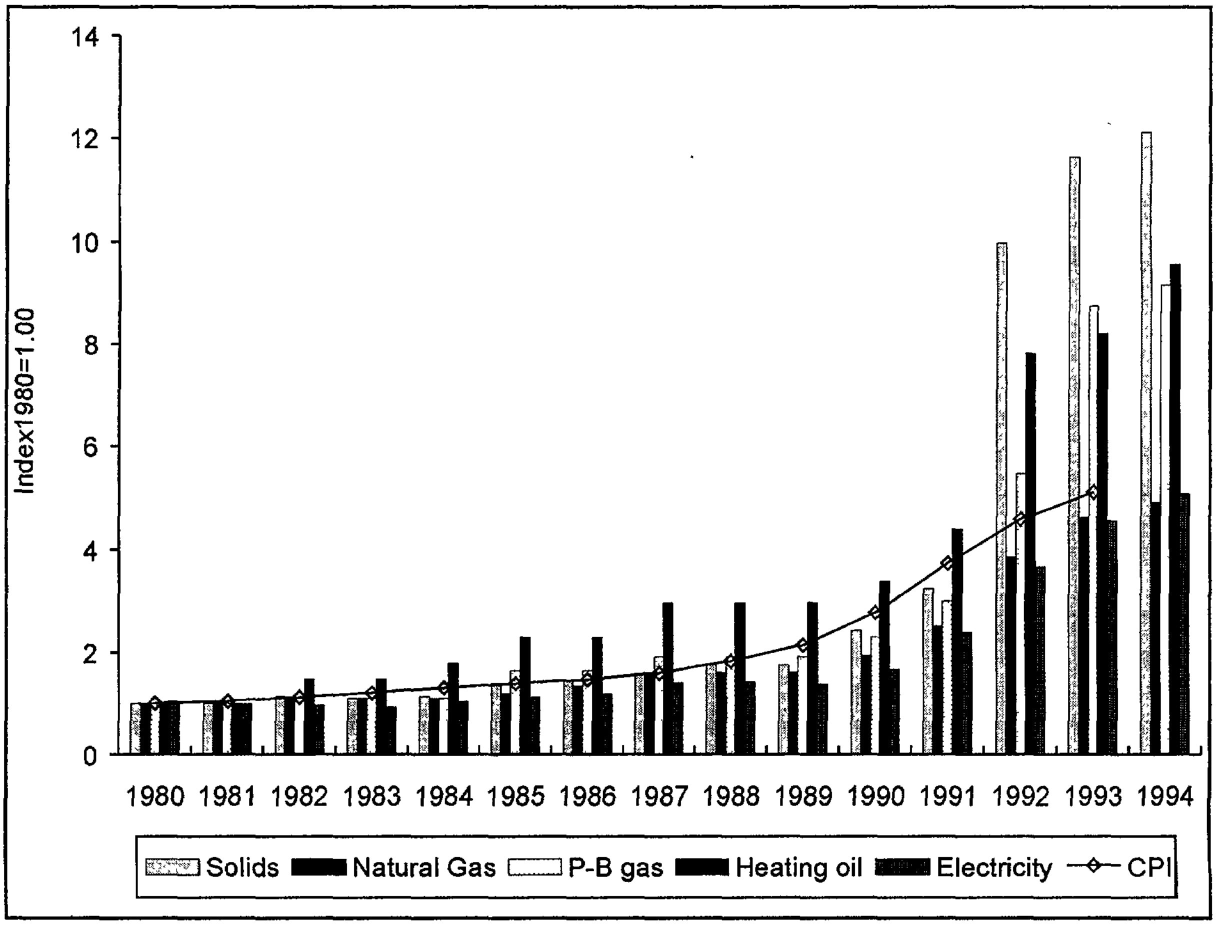
5.1 Energy use in Hungary: before and after the transition

Before 1989 Industry was responsible for almost 50% of final energy consumption in Hungary, with the residential sector consuming 30%, and services just 15%.

Since 1989, the structure of energy consumption has changed dramatically. With the domestic market in extreme recession and COMECON trade relationships failing, industry has contracted sharply, with consequent falls in energy consumption. These reductions have not taken place uniformly across the sector, with technologically outdated branches falling furthest. The main energy carriers were affected quite evenly, and there is little evidence of inter-fuel switching.

Residential energy consumption also displayed a fall during 1991/1992. However, there is strong evidence of inter-fuel switching during 1991 and 1992. The major switch appears to be from solid fuels for heating to natural gas but there is evidence also of some movement back to heating oil., previously regarded as too expensive. Price changes during the transition appear to underlie the reverse in this trend.

Figure 2 shows the movement of prices for the major fuels in the residential market. Prices are represented by a current price index for January of each year, with the Consumer Price Index (CPI) overlaid. It is evident that during the 1980s the price of heating oil rose faster than the CPI. However, in 1992 and 1993, whilst oil prices still rose faster than the CPI, the price of solid fuels rose even faster, more than doubling during this period. Such rises were the driving force for reversion to oil heating. In general, prices for industry in Hungary are thought to approach market levels. For residential customers, the prices of both electricity and natural gas are still subsidised.



5.2 Modelling the future pattern of demand - development of base scenario

There is great uncertainty attached to the projection of economic development in Hungary. Despite movement towards market mechanisms, the pattern of industrial recovering will be strongly influenced by Government policy. This influence may be direct, through the provision of finance to certain branches and the programme of privatisation. Equally, influence may be indirect, through the effect of residual price controls, but it is clear from policy statements that control has not been fully relinquished (Hungarian Ministry of Trade and Industry 1993). For this reason, the projections for medium term economic development are based on the goals set by the Hungarian Government. In the longer term, the economic structure is expected to align more closely with those found in Western Europe today. The present OECD average economic structure is therefore used as a target for 2010.

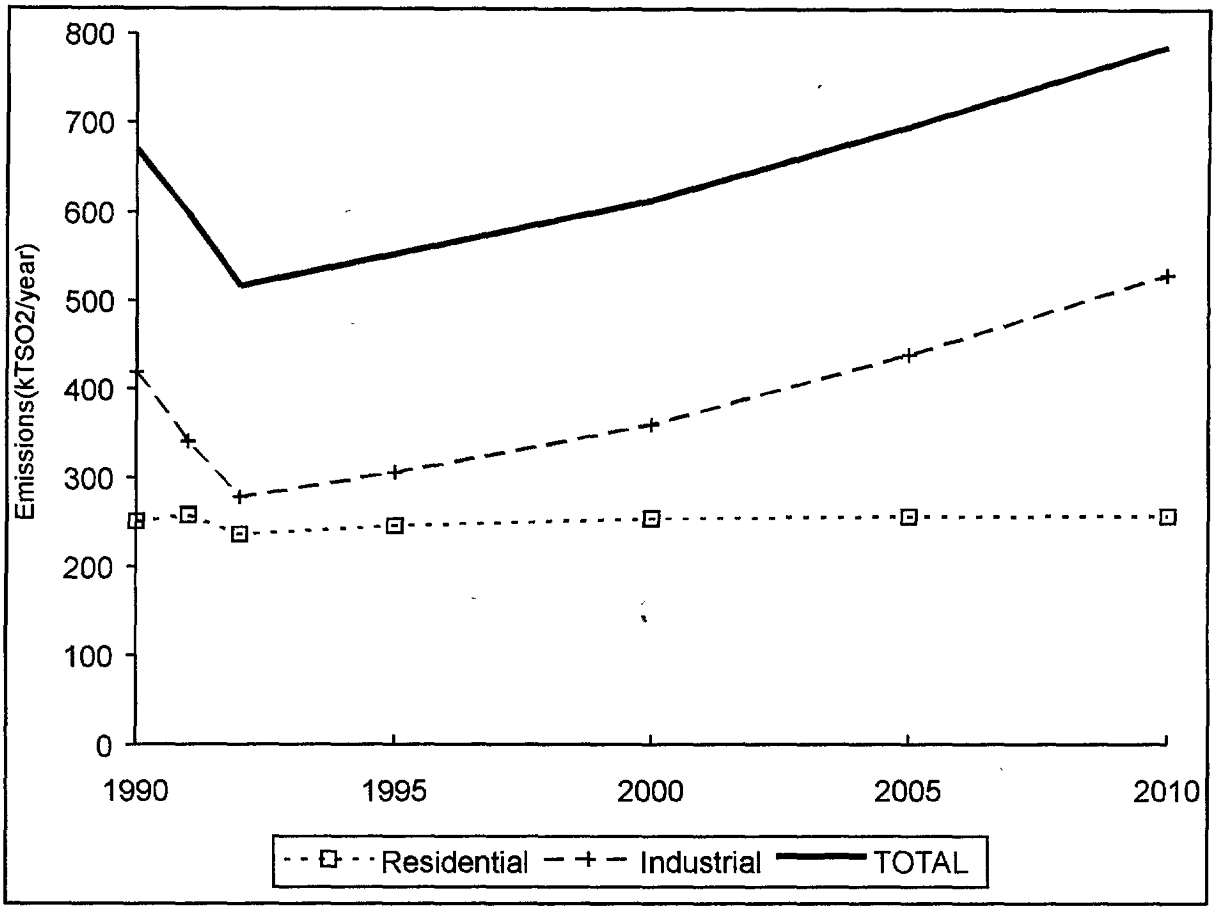
The demands for energy services are projected to rise for both residential and industrial consumers. As household incomes rise the average dwelling floor area is expected to increase, resulting in higher demands for heating. However, this trend will be offset to an extent by a continued migration from rural to urban areas. Ownership levels for domestic appliances are also expected to rise. However, the large price rises which are required to bring residential electricity prices closer to those found in Western Europe are expected to slow this process substantially. Relatively small increases in energy service levels are therefore assumed in the base scenario. The potential for increased market penetration of appliances forms a core part of this study of technology diffusion.

In the industrial sector, once stability has returned rising production will lead to a growth in energy consumption - without specific policy support, energy efficiency improvements are not expected to have a major impact. In addition, during the transition the number of industrial organisations has grown very rapidly, as large organisations have fragmented. This process will increase aggregate industrial energy consumption, as economies of scale in process heat production and steam-raising are lost. In the base scenario only modest improvements in efficiency of the stock of energy end-use technologies are assumed.

The implications of the base scenario for emissions of Sulphur Dioxide are shown in Figure 3. Underlying these trends are various changes in energy carrier demand. In the residential sector, the use of natural gas continues to increase as distribution network expansion continues. Increasing urbanisation also acts to raise natural gas use, as more households are established in reach of the existing distribution infrastructure. Decline in use of solid fuels slows from 1992 onwards, as the ability by households to switch back to heating oil is exhausted. Growth in electricity consumption is markedly slow, due mainly to the assumptions about slow appliance penetration described earlier. However, replacement of electric room heaters with the use of natural gas is also important.

In the industrial sector, total energy consumption falls by approximately thirty percent between 1990 and 1992. From then on, demand increases quite slowly, and does not return to 1990 levels until 2004. The trend for each energy carrier is quite similar, resulting from the assumption of limited inter-fuel substitution and conservation activity.

Overall, despite the effect of economic recession, emissions are expected to return to pre-transition levels early in the next century, and continue to rise thereafter.



5.3 Enhancing energy efficiency - examples

Starting from the position described in the base scenario, many strategies for improvement of energy efficiency could be elaborated. As already mentioned, such tools as fuel pricing policy, information campaigns and direct subsidy or tax breaks can be represented in the model through their effect on the set of technology diffusion curves. For the sake of clarity, the focus here is on just one policy instrument: the effect of subsidies for the purchase of more efficient end-use equipment or conservation retro-fits. Whilst the actual application of subsidies per-se is controversial, the analysis is intended to indicate the potential of conservation activities when compared to expenditure on energy-supply structures. Moreover, the subsidy process best represents the possibilities for Western investment in pollution abatement in the East, as has been explored recently by Haas (1994) and Wirl (1994).

As already mentioned, the diffusion of just one example technology is considered in this paper. However, the model can be used to analyse the diffusion of single technologies or of many technologies simultaneously: the Partial and Integrated approaches to diffusion modelling respectively (Morthorst 1994). In a full simulation it is desirable to use the integrated approach, to capture interactions between the impact of each technology. For example, the installation of loft insulation becomes financially less attractive as the stock of space heating equipment becomes more efficient or as consumers switch towards cheaper fuel.

5.3.1 *Example: Residential draught exclusion*

Within the stock of housing with poor to medium levels of thermal insulation and building integrity in Hungary, there is a great opportunity to reduce energy consumption for space heating through reducing draughts. The Buildings Maintenance R&D Foundation in Budapest (1993) estimate that on average consumption may be reduced by 4% through a relatively low cost package of measures involving facade window and door sealing. The payback time for the measure is therefore short, at one to two years. However, since the measure is most appropriate for dwellings in a poor state of repair, many of the relevant households are in low income groups. The required investment may therefore be equivalent to as much as 100% of a households monthly disposable income. The uptake of the measure is therefore slower than might be expected through consideration of the payback characteristics alone: the time to 50% saturation is estimated to be around 25 years.

The effect of reducing the apparent cost of the measure to the household through a subsidy on the pre-tax retail price can now be considered.

By running the energy model for each level of subsidy, the energy savings, emission savings and total cost implications in each case may be calculated . Figure 4 shows the impact which the draught proofing measure makes on annual emissions of Sulphur Dioxide, when diffusion is supported by a 60% subsidy. Emission savings rise rapidly, as the diffusion curve is in the stage of initial fast growth. The different contributions made to the total saving by each fuel result from both differences in Sulphur Dioxide emissions per unit of heat output and the pattern of space heating equipment ownership.

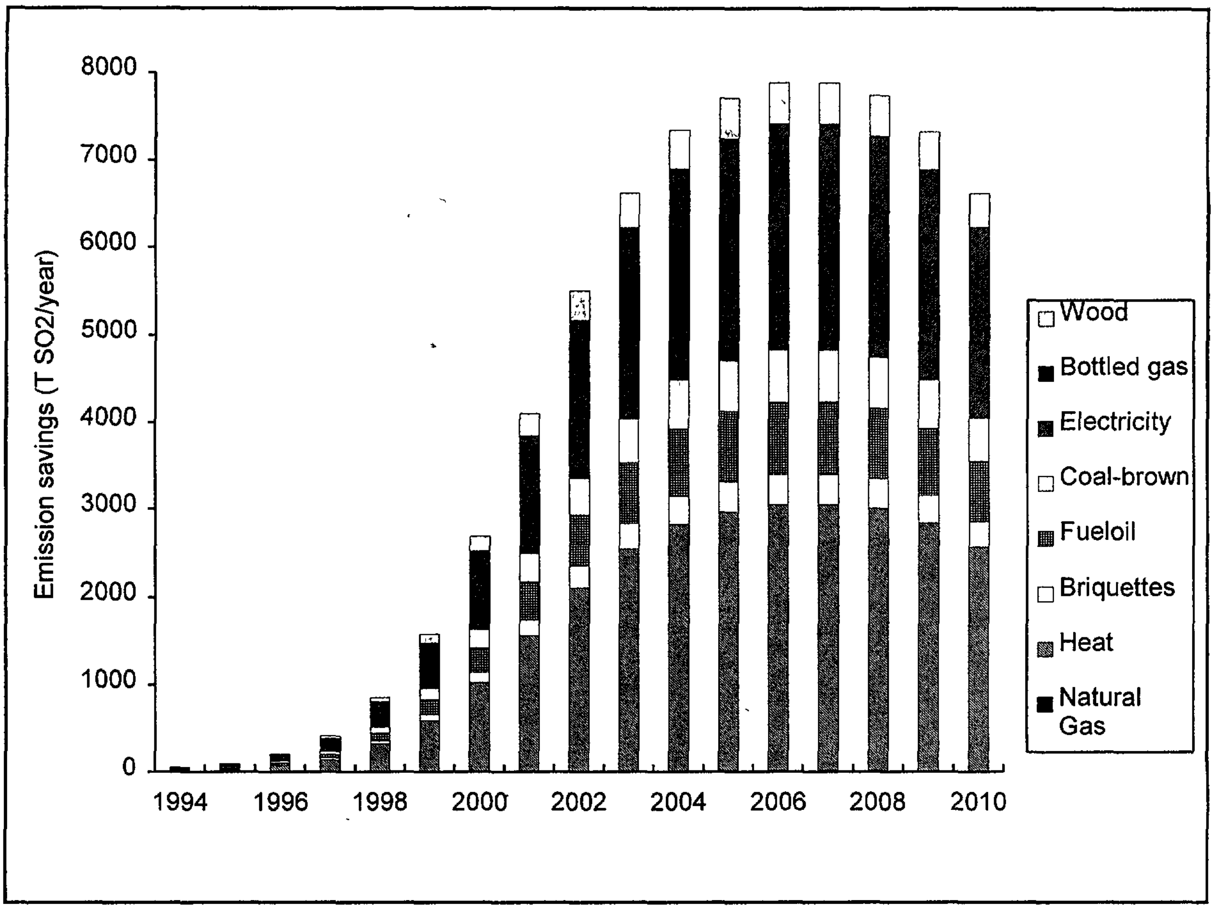
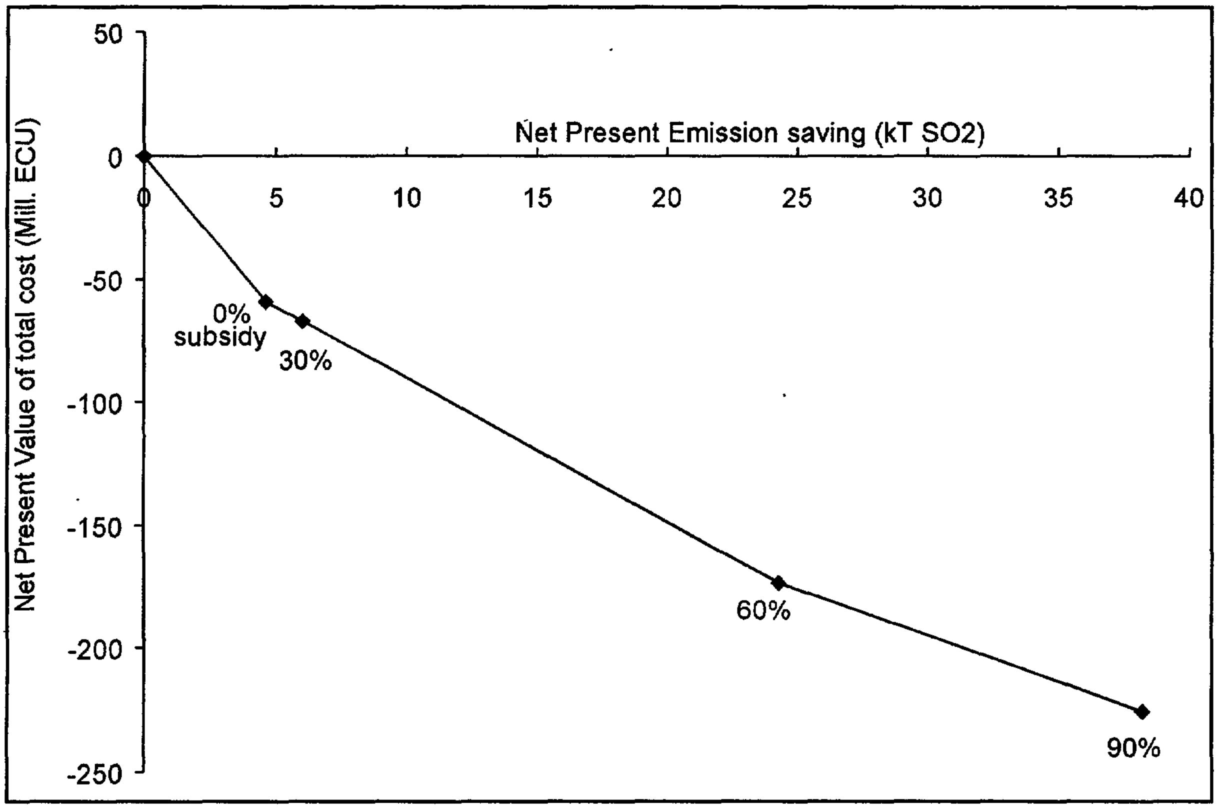


Figure 5 shows the discounted total emission savings plotted against net present total cost, for successive levels of subsidy. The net present total cost, representing the sum of user capital investment, subsidy transfer cost and user savings on fuel expenditure is negative for all levels of subsidy. However, as the subsidy rises the slope of the line joining each point decreases, indicating that the marginal benefit is decreasing.



Putting the level of emission savings into perspective, eight thousand tonnes reduction in annual emissions of Sulphur Dioxide is equivalent to around one percent of the emissions expected in Hungary in 2010 under the reference case of the CEC's Energy 2010 study (Rentz et al, 1994). Whilst this saving is not large in itself, this abatement measure is just one of a large number of possible options for energy conservation activity.

Appraised in terms of social cost, this efficiency measure is clearly very attractive. If the policy measure is assessed not from the point of view of society, but from the point of view of a government investing to reduce emissions, the most important measure may be the total subsidy payments. Rentz et al (1994) show an abatement cost curve for Hungary generated from EFOM-ENV, in which the cheapest options abate emissions in 2010 at 1500 ECU(1985 value) per Tonne of Sulphur Dioxide saved. Similar analysis for the policy option of a 30% subsidy on draught proofing yields a cost of around 400 ECU/Tonne.

6 .CONCLUSIONS

Emissions of Sulphur Dioxide and other pollutants are expected to increase in Hungary and other of the countries in transition, as recovery from recession continues and standards of living rise. Whilst much attention is already focused on these problems, excessive weight is given to abatement options in the energy supply industries rather than to options to reduce energy demand and increase the efficiency with which energy is used.

The role of policies to enhance existing diffusion or adoption of efficient technologies is important for Eastern and Central Europe, where market failures and capital scarcity presently limit such diffusion.

Analysis of full social costs for efficiency measures frequently demonstrates that energy and pollution savings can be made at negative cost. To the policy maker, such information is rarely of practical use, since competing demands for investment narrows the practical field of view from the welfare of society to the efficiency of an option for a specific purpose. It is therefore important to present information on efficiency measures in a form in which it may be more readily compared with other investments. As the work proceeds, the results from analysis of a wide range of efficiency measures in the residential and Industrial sectors will be formed into a series of cost curves.

Preliminary analysis suggests that there are a wide range of efficiency measures which deserve further support in Hungary, as they offer significant emissions abatement potential and are economically attractive.

The database management system approach for the model has proved useful, minimising the problems of data storage and manipulation commonly encountered in end-use energy demand modelling. The final modelling tool enables the rapid development of new scenarios and a high degree of transparency, allowing insights into the essential features underlying the energy systems in transition.

7. ACKNOWLEDGMENTS

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