ENERGY-ECONOMY-ENVIRONMENT MODELLING FOR TURKEY

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Prof. Dr. Tayfur Öztürk
Director

I certify that this thesis satisfies all the requirements as a thesis for the degree of Doctor of Philosophy.

Prof. Dr. Nesim Erkip
Head of Department

This is to certify that we have read this thesis and that in our opinion it is fully adequate, in scope and quality, as a thesis for the degree of Doctor of Philosophy.

Prof. Dr. Çağlar Güven
Co-Supervisor

Assoc. Prof. Dr. Yıldız Arıkan
Supervisor

Examining Committee Members

Prof. Dr. Merih Celasun

Prof. Dr. Nesim Erkip

Prof. Dr. Çağlar Güven

Assoc. Prof. Dr. Yıldız Arıkan

Assoc. Prof. Dr. Sinan Kayalıgil

ABSTRACT

ENERGY-ECONOMY-ENVIRONMENT MODELLING FOR TURKEY

Kumbaroğlu, Gürkan Selçuk

Ph.D., Department of Industrial Engineering
Supervisor: Assoc. Prof. Dr. Yıldız Arıkan
Co-Supervisor: Prof. Dr. Çağlar Güven

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This dissertation investigates the interdependency between the economic and environmental aspects of alternative energy policies for Turkey and discusses rational strategies. In this respect, a systems model is developed that combines a detailed energy model with a single-sector economic growth model and an environmental submodel. The submodels are linked in such a way that the integrated model allows for feedback effects, both from the energy sector and the environment to the economy as well as from the economy to the energy sector and environment. The long-term view of the model permits a dynamic comparison of alternatives and provides a consistent framework for policy analysis. The model is calibrated using Turkish data to produce equilibrium solutions that maximise utility over the planning horizon.

Model results show that Turkey can reduce its pollutant emissions to the levels implied by European standards with little sacrifice from economic growth provided that rational energy and economic policies are applied. The results indicate that a transitionary agreement allowing less stringent emission standards for Turkey in early European Union membership years is in the long run not an advantage for the country if more stringent standards are to be adopted later on. Moreover, model solutions point out the importance of nuclear electricity for Turkey and suggest not to follow anti-nuclear policies in spite of the uncertainties regarding the expected cost of nuclear power generation. The results further indicate that nuclear energy restricting policies inflate the bill of reducing air pollutant emissions and also increase Turkey's dependence on fuel imports. It should be noted, however, that the findings are dependent on the set of input assumptions adopted in the model.

Keywords: Energy Planning, Energy-Economy-Environmental Interactions, Energy Policies in Turkey, Energy-Economy-Environmental Integrated Assessment Modelling, Single Sector Economic Models, Systems Modelling.

ÖZ

TÜRKİYE İÇİN ENERJİ-EKONOMİ-ÇEVRE MODELLEMESİ

Kumbaroğlu, Gürkan Selçuk

Doktora, Endüstri Mühendisliği Bölümü
Tez Yöneticisi: Doç. Dr. Yıldız Arıkan
Ortak Tez Yöneticisi: Prof. Dr. Çağlar Güven

Şubat 2001, 159 sayfa

Bu tezde Türkiye için alternatif enerji politikalarının ekonomik ve çevresel etkileri irdelenerek akılcı stratejiler tartışılmaktadır. Bu çerçevede, ayrıntılı bir enerji modelini tek sektörlü bir ekonomik büyüme modeli ve bir çevre altmodeli ile birleştiren bir sistem modeli geliştirilmiştir. Modelde enerji sektörünün çevreye ve ekonomiye etkileri tanımlanmış olduğu gibi ekonomiden enerji sektörüne ve çevreye geri besleme ilişkileri de içerilmiştir. Uzun dönemli yapısı nedeniyle model alternatif politikaların dinamik karşılaştırılmasına olanak sağlamakta ve böylece politika analizleri için tutarlı bir temel oluşturmaktadır. Türkiye verileri kullanılarak kalibre edilen model ile planlama dönemi boyunca fayda maksimizasyonu sağlayan denge çözümleri alınmıştır.

Model sonuçları, Türkiye'nin akılcı enerji ve ekonomi politikaları uygulayarak ekonomik büyümeden fazla ödün vermeden emisyonlarını Avrupa standardlarına getirebileceğini göstermektedir. Model sonuçları, Avrupa Birliğine girişte üyeliğin ilk yıllarında daha fazla emisyona izin veren bir anlaşmanın yapılmasının uzun vadede Türkiye'nin çıkarına olmayacağını ortaya koymaktadır. Bu sonuçlar üyeliğin ilerki tarihlerinde Avrupa Biriliği'nin kısıtlayıcı standardlarına uyma zorunluluğu gözönüne alınarak elde edilmiştir. Bunun yanısıra model sonuçları nükleer enerjinin kalkınmadaki önemini ortaya koymakta ve nükleer enerji üretim maliyetlerindeki belirsizliğe rağmen nükleer karşıtı politika güdülmemesi gerektiğini göstermektedir. Ayrıca sonuçlar nükleer enerji kısıtlayıcı politikalar sonucu hava kirletenleri emisyonlarını azaltmanın faturasının daha ağır olacağını ve ülkenin ithal yakıtlara olan bağımlılığının artacağını göstermektedir. Ancak elde edilen bulguların modelin varsayımlarına bağlı olduğu gözardı edilmemelidir.

Anahtar Kelimeler: Enerji Planlaması, Enerji-Ekonomi-Çevre Etkileşimleri, Türkiye'de Enerji Politikaları, Enerji-Ekonomi-Çevre Entegre Modellemesi, Tek Sektörlü Ekonomik Modeller, Sistem Modellemesi.

To my mom Gülay and dad Sabri,

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TABLE OF CONTENTS

CHAPTER

APPENDICES

LIST OF TABLES

TABLE

LIST OF FIGURES

FIGURE

LIST OF SYMBOLS AND ABBREVIATIONS

ABBREVIATIONS

AEE : Aggregate Economic Equilibrium
AEEI : Autonomous Energy Efficiency Improvement
BAU : Business As Ususal
Btu : British Thermal Unit
CES : Constant Elasticity of Substitution
CGE : Computable General Equilibrium
DEE : Disaggregate Economic Equilibrium
EMI : Emission Intensity
ENI : Energy Intensity
ESE : Energy Sector Equilibrium
ESO : Energy Sector Optimisation
EU : European Union
GDP : Gross Domestic Product
Gwh : Gigawatthour
Koe : Kilos of Oil Equivalent
Kcal : kilocalories
Kwh : Kilowatthour
Mtoe : Million Tons of Oil Equivalent
Mw : Megawatt
NO_x : Nitrogen oxides
SO_2 : Sulphur dioxide
Ttoe : Thousand Tons of Oil Equivalent
Twh : Terrawatthour

VARIABLES

$\alpha(EI)$: Environmental preference rate depending on emission index
$\beta(EITX)$: Environmental preference rate depending on emission index-tax aggregate
C : Total consumption
CG : Imports of consumption goods
CO : Primary energy consumption
$COAL$: Coal consumption for nonelectric use
DNE : Domestic fuel consumption for nonelectric use
DP : Domestic fuel production
E : Electricity aggregate

EC : Total energy cost
EF : Cost of fuel imports
EI : Emission index
$EITX$: Emission index – tax aggregate
$ELEC$: Electricity consumption
EN : Newly installed power plants
$EPOL$: Pollutant emissions originating from power generation
F : Foreign capital inflows
FCO : Imported fuel consumption
$FILT$: Amount pollutant filtered by abatement activities
FNE : Imported fuel consumption for nonelectric use
$FUEL$: Total fuel consumption
G : Government expenditures
GAS : Natural gas consumption for nonelectric use
GDP : Gross domestic product
I : Investments
ID : Domestic money component of investments
IF : Investments made with foreign capital goods
INT : Imports of intermediate goods excluding fuels
$INTN$: Newly added incremental imported intermediates
IT : Intersectoral transactions
K : Capital stock
KN : Newly added incremental capital stock
KD : Domestic capital stock
KDN : Newly added incremental domestic capital stock
KF : Foreign capital stock
KFN : Newly added incremental foreign capital stock
L : Labour stock
$LIG1$: Type 1 lignite consumption for nonelectric use
$LIG2$: Type 2 lignite consumption for nonelectric use
$LIG3$: Type 3 lignite consumption for nonelectric use
$LIG4$: Type 4 lignite consumption for nonelectric use
LN : Newly added increment of labour
M : Total imports
NE : Nonelectric energy consumption
$NEPOL$: Pollutant emissions from nonelectric energy consumption
NOX : Total NO_x emissions
NX : Net exports
P : Oil and gas aggregate
PET : Petroleum consumption for nonelectric use
$PETD$: Consumption of domestic petroleum for nonelectric use
$PETI$: Consumption of imported petroleum for nonelectric use
PN : Newly added increment of oil&gas
POL : Amount of x type pollutant emissions in year t
PR : Pollutants filtered by abatement activities
S : Solids aggregate
SN : Newly added increment of solids
$SO2$: Total SO_2 emissions

$TAX1$: Emission tax
$TAX2$: Sulphur tax
TR : Tourism revenues
U : Total household utility
W : Factor incomes from abroad
X : Total exports
Y : Gross production

INDICES
i : Index for sectors
j : Index for energy types
k : Index for subenergy types
l : Index for sectors
s : Index for emission control technologies
t : Index for years which represent periods
T : Terminal period
x : Index for pollutant types

PARAMETERS AND CONSTANTS
λ : Annual survival factor ; $(1-\lambda)$ denotes stock depreciation.
$\mu,\phi,\eta,\gamma,\alpha,\beta,\theta, o, \nu, \phi, \kappa$: Scale parameters
δ : Annual cost and utility discount rate
c : Unit cost of energy acitivities
e : Required thermal fuel for unit electric production
EI_{max} : Maximum emission index
$EITX_{max}$: Maximum emission index-tax aggregate
NOX_{Base} : Base year NO_x emissions
p : Period length in years
prc : Unit cost of emission reduction technologies
$SO2_{Base}$: Base year SO_2 emissions
sd : Sectoral distribution of nonelectric energy
sk : Value share of capital within capital-labor pair
skd : Value share of domestic capital within domestic and foreign cap.
se : Value share of electricity within energy aggregates
skf : Value share of foreign capital within domestic and foreign cap.
sl : Value share of labor within capital-labor pair
sp : Value share of oil&gas within energy aggregates
ss : Value share of solids within energy aggregates
t : Environmental tax rate
w : Weight of pollutants in the emission index

CHAPTER I

INTRODUCTION

Global environmental issues are of increasing concern worldwide. Concern is being expressed at both the national and the international level on the consequences of environmental pollution as a result of human activity. Pollutant emissions, a by-product of our production and consumption activities, are known to affect ecological balances and give rise to natural disasters and threaten human health. Triggered by the commitment to take environmental considerations into account in their social and economic policies and to implement measures for mitigating pollution under the UN Framework Convention (1992), various international agreements have focused on environmental issues, as for example the Berlin Mandate (1995) and the Kyoto Protocol (1997), and have proposed a variety of targets and timetables for pollutant emission reductions.

Various measures for reducing pollutant emissions exist; emission charges, tradeable permit systems, environmental taxes, performance bonds, liability payments and non-compliance fees can be stated as some examples currently in use. The setting of emission quotas by issuing tradeable certificates of emission permits and the introduction of environmental taxes emerge from the Intergovernmental Panel on Climate Change Report (1996) as potentially effective market instruments that should be taken into consideration. The latter policy instrument has received much international attention in recent years, the OECD is currently developing a database with detailed information on environmental related taxes in member countries. An environmental charge on energy products has already been introduced in Denmark, Finland, Norway, Sweden, the Netherlands, Italy and the UK.

The use of emission permits and taxes contributes to preserve environmental quality. The environmental effectiveness of those instruments, their economic effects and associated welfare implications are of primary importance for policy-makers who decide on environmental and economic policies. The international scientific community devotes therefore much research effort to find out about interactions between industrial development and environmental degradation. These interactions are based on an inter-play between key elements of the energy and the economic system like energy consumption patterns, the technological structure and flexibility of the energy system, fuel properties, energy security, capital stock, import composition, foreign exchange availability, household income, available investment capital, etc. The complexity of the interdependencies and the long time scales needed to observe them make it difficult to handle the problem. Systems models which integrate ideas and methods from several disciplines are presently the primary analytical tool available to study such complex interdisciplinary problems. Considerable advance in computer technologies and the parallel development of efficient solution algorithms in the last decade have encouraged modellers to construct large-scale systems models for integrated energy-economy-environmental studies. These models combine various submodels like for example energy balance models, economic equilibrium models, atmospheric circulation models, or damage assessment models to address the complex interactions between energy, economy and the environment.

In trying to bring a broad system-wide perspective into the analysis, modellers have resorted to all sorts of approaches and methodologies. Optimum and equilibrium seeking approaches as well as econometric methods are among the basic assessment tools. Of these, econometric modelling has been less useful in energy-economy-environmental modelling because the methodology cannot handle sudden price movements and energy representations are highly aggregated. Optimum and equilibrium seeking approaches emerge as two fundamental approaches, with different scope and balance of detail, which are most commonly applied in energy-economy-environmental integrated modelling studies. Optimum seeking approaches aim to maximise or minimise a single objective function under a set of constraints. Although optimum seeking models like for example GLOBAL 2100 (Manne et al., 1994) or CETA (Peck et al., 1994) are large-scale and rich in energy detail, they treat the rest of the economy in a more aggregate fashion: consumption is usually determined as an aggregate, GDP is obtained with an aggregate production function etc. Economic relationships in these models are rather 'ad-hoc' and less consistent with consumers' utility and producers' profit maximisation. Equilibrium seeking models on the other hand include various economic agents and simulate their optimising behaviours based on microeconomic foundations. In other words, they contain economic relationships which are derived from consumers' utility and producers' profit maximisation. Equilibrium seeking models are either of the partial equilibrium or of the general equilibrium type. A partial equilibrium model like for example GEMINI (Cohan et al., 1994) or WATEMS-GDL (Chung et al., 1997) incorporates selected sectors of the economy, assuming all others remain unchanged. A general equilibrium model on the other hand, like for example GOULDER (Goulder, 1994) or PESTES (Beaumais et al., 1995), contains all sectors of the economy. Equilibrium seeking applied energy-economy-environmental models are usually of the computable general equilibrium (CGE) type. Recently developed modelling software like for example GEMPACK (Harrison et al., 1995) or MPSGE (Rutherford, 1995) facilitated the solving of large-scale dynamic general equilibrium models and encouraged modellers to develop CGE models of energy, economy and environmental interactions. These models represent the economy as a set of interrelated markets; they consider markets by industry category and set up as a system of supply-demand equations for all of the markets involved. Accordingly, CGE models can handle more subsectors and focus on sectoral interactions; GDP is allowed to be partly determined by inter-industry interactions. The multisectoral structure of the CGE models enables to account for sectoral differences in pollutant emissions. The economic impacts of pollution reducing economic instruments like taxation are more realistically represented in these models because of the underlying microeconomic foundations. A CGE model allows accordingly to integrate various tax structures of the economy, to represent the return of tax revenues back to the economy via public expenditures or via a reduction in other taxes in a detailed manner and to explore welfare effects. The disaggregated economic representation in CGE models however tends to restrict disaggregation of any one industry such as the energy sector due to computational difficulties as well as due to problems in defining interindustry relations. The lack of reliable appropriate data at a level of detail required by the model is a common problem in CGE modelling. The choice regarding which technique to apply will depend upon the focus of analysis.

This thesis aims to investigate the interdependency between the economic and the environmental aspects and outcomes of energy policies for Turkey. In this respect, a systems model is developed that combines a detailed energy model with a single-sector economic growth model and an environmental submodel. The submodels are linked in such a way that the combined model allows for feedback effects, both from the energy sector and the environment to the economy as well as from the economy to the energy sector and environment. The economy is represented in the model by an aggregate production function in which capital, labour and different energy forms are intermediate inputs to determine GDP. A disaggregated energy representation is adopted which features a detailed representation of pollutant emissions. The model constitutes a consistent framework for the elaboration of interdependencies between energy policies, the economy, and the environment and is suitable for making a range of policy analyses for Turkey.

This thesis reports in particular on experimentation that aims to endogenise pollution abatement and emission taxes. A pollution abatement endogenising model specification is developed by incorporating an emission dependent quality-of-life

penalty function into the utility function as an alternative way of treating the environmental impact of energy activities. Another specification that endogenises emission taxation is developed by incorporating a preference rate into the utility function which is related both to the level of emission tax and to pollutant emissions.

The model is calibrated and applied using Turkish data. Results are obtained under a Business-As-Usual (BAU) reference scenario as well as several environmental policy scenarios that introduce European emission standards and non-environmental scenarios that simulate various current energy policy issues. Results of the environmental and non-environmental scenarios are compared with BAU projections and policy implications are discussed.

Model results show that Turkey can reduce its pollutant emissions to the levels implied by European standards with little sacrifice from economic growth. It is found that the GDP losses implied by an adaptation of European emission standards remain below 1.5% of GDP until 2030 Achieving this will require to follow rational strategies that introduce efficient economic measures for pollution abatement and make use of carefully selected energy alternatives. Results of the solutions indicate that such choice are feasible. Implications of differing scenarios are such that a transitionary agreement allowing less stringent emission standards for Turkey in early European Union (EU) membership years is in the long run not in the advantage of the country if more stringent standards are to be adopted later on. Solutions reveal the importance of nuclear power for economic development in

Turkey and suggest not to follow anti-nuclear policies in spite of the uncertainties regarding the expected cost of nuclear power generation. Results indicate that a limit on nuclear energy causes considerable economic losses unless new alternatives are developed. Results also show that nuclear energy restricting policies inflate the cost of reducing pollutant emissions. It is further found that anti-nuclear policies increase dependency on fuel imports so that the Turkish economy becomes more sensitive to imported energy price variations.

Contributions of this research are as follows. First, it is the development of a combined interdependency framework which represents the interplay between energy, economy and the environment. A second contribution is the proposed integration of environmental externalities into the utility function which is to our knowledge a first effort in this area. Another contribution is the achievment of policy implications which point out the importance of nuclear electricity for Turkey and which indicate that, under rational energy policies, Turkey can reduce its pollutant emissions to European levels without slowing economic growth too much.

The following chapter provides a literature survey on integrated assessment modelling studies highlighting main characteristics and original features of various models. Chapter 3 includes a general overview on the mutual relationships between energy, economy and environment, and discusses the Turkish situation presenting perspectives from the national energy system, the Turkish economy as well as the country's environmental regulations. Main features of the one-sector energy-economy-environmental model, its underlying assumptions and experimentation to endogenise pollution abatement and environmental taxes are described in chapter 4. The following chapter explores model validity, presents numerical results and discusses various energy policies for Turkey. Finally, overall conclusions are evaluated in chapter 6. Issues requiring further work are also pointed out.

CHAPTER II

A SURVEY OF THE LITERATURE ON ENERGY STUDIES

Recent trends in energy modelling are reviewed in this chapter. *Integrated assessment modelling* is identified as the fundamental trend in current generation energy studies. Several models of this class are discussed highlighting principal characteristics and novel features. The incorporation of environmental taxation in energy models is discussed in particular. The chapter ends with a discussion of problematic issues in integrated energy-economy-environmental modelling studies.

2.1. Introduction

Models constructed for energy policy analyses have evolved in parallel to the development of modelling techniques and solution algorithms. Since the development of the simplex method by George B. Dantzig in 1947, linear programming has found application in planning including energy planning. The number of energy models reported has been limited until the oil crisis of 1973, which then increased both in terms of quantity and quality. The crisis years led people to witness the strong connections between energy and economic activity and triggered the modelling of energy-economy interactions. However, due to the large scale and greater complexity of integrated energy-economy models, their scope and capabilities were built up gradually in time in parallel to the development of modelling techniques and solution algorithms. Increased concern for the environment since the eighties stimulated the inclusion of environmental modules in energy models and integrated models of energy, economy and environmental interactions began to appear. Thus quantitative models for energy planning started with simple energy-sector models, evolved with the integration of macroeconomic growth models, and recently have developed into integrated assessment models that incorporate environmental issues. Integrated assessment models are defined as models that integrate ideas and methods from several disciplines. By definition, any combination of energy, economy and environmental model results in an integrated assessment model.

All integrated assessment models include some form of optimisation in their formulation, however a distinction can be made as to whether there is a single objective function in the model or whether there are several agents in the model which have different behaviours and simultaneously try to solve different optimisation problems. The single-objective-function models are classical 'optimisation models' in the form

$$\begin{aligned} &\text{max. (or min.) } f(x) \\ &\text{Subject to } g(x) = 0 \\ &\qquad\qquad l \le x \le u \end{aligned}$$

where x represents decision variables, l and u are lower and upper bounds respectively, and f and g are functions in the form of $f:R^n \to R$ and $g:R^n \to R^m$.

Multiple-agent models on the other hand inherit simultaneously several optimisation problems of the type shown above. That is, there is a producer who maximises profits subject to technological constraints and at the same time there is a consumer who maximises utility subject to his budget constraint. These problems are simultaneously solved on the basis of optimality conditions derived from the agents' problems to yield a Pareto-efficient solution, i.e. a solution in which no agent can be made better off without making any other worse off. The Pareto-efficient solution is called an equilibrium solution and these models are therefore referred to as 'equilibrium models'. The equilibrium conditions are accommodated into the model and the resulting formulation is called a mixed complementarity problem (MCP). The general MCP format is defined as follows (Böhringer, 1999):

$$
\begin{aligned}
&\textit{Find } z,\ w,\ v\\
&\textit{Subject to } F(z) - w + v = 0\\
&\qquad l \le x \le u,\ w \ge 0,\ v \ge 0\\
&\qquad w\,(z-l) = 0,\ v\,(u-z) = 0
\end{aligned}
$$

where z is the decision variable, v and w denote slack variables, l and u are the lower and upper bounds respectively and the function F is of the form $F\colon R^N \to R^N$. The general formulation above can take various special forms based on market-specific equilibrium conditions like for example Nash equilibrium (Nash, 1951) or Walrasian equilibrium (Jehle, 1991) arising in equilibrium theory.

2.2. Integrated Assessment Models Representative of Recent Work

Energy-sector and energy-economy models will not be elaborated here (interested readers may refer to Searl (1973), Shapiro (1975), Manne et al. (1979), Lev (1983) or Kavrakoğlu (1987)); the focus will be on the last generation of energy-environment and energy-economy-environmental models.

Integrated assessment models of energy-environment and energy-economy-environment, coming up from a combination of energy, economy, environment, climatic and damage assessment submodels, have recently been proposed in order to simultaneously evaluate energy, economic and environmental policies. A variety of schemes can be proposed to classify integrated assessment models. A fundamental characteristic is the models' market representation, which also is an indicator of the modelling approach used. Using the terminology of the Energy Modeling Forum (Beaver, 1994) there are aggregate economic equilibrium (AEE) models which usually are nonlinear optimisation models, disaggregate economic equilibrium (DEE) models which are of the computable general equilibrium (CGE) type, energy sector equilibrium (ESE) models which make use of partial equilibrium theory and energy sector optimisation (ESO) models which are linear optimisation ones. Models can also be differentiated according to their scope; a model with regional scope will feature an analysis on the international trade of emission certificates. Another distinguishing characteristic is the time horizon used: it is either short (less than 30 years) or medium (between 30 and 60 years) or long (more than 60 years) depending on the model structure and the focus of the analysis. Based on these characteristics, Table 2.1 presents a classification of twenty integrated assessment models that are representative of recent work.

Table 2.1. Classification of Recent Models

	Market representation				Time horizon			Scope	
Model	DEE	AEE	ESE	ESO	short	med.	Long	nation	region
MOBI-DK	*					*			*
GOULDER	*				*			*	
PESTES	*						*	*	
JW	*						*	*	
MULTI	*						*	*	
WARM	*				*				*
DREAM	*						*	*	
CETA		*					*		*
MERGE		*					*		*
GLOBAL2100		*					*		*
MIS		*			*			*	
RICE		*					*		*
IIAM		*			*				*
GEMINI			*		*			*	
ERB			*				*		*
ICF			*				*		*
WATEMS-GDL			*			*		*	
MARKAL				*	*			*	
MRMM				*			*		*
EFOM-ENV				*	*			*	
PERSEUS-GWI				*			*	*	

Six of the surveyed models are AEE models and seven are DEE ones. The total of ESE and ESO models reaches eight; there are four representative models in each category. Since the market representation is an essential fundamental characteristic and an indicator of the modelling approach, each category is elaborated in more detail in the sections to follow.

Given the nature of global warming issue, it can be seen from Table 2.1 that the time horizons are typically long usually extending over a century; the shortest horizons provide estimates for the next 25-30 years (e.g. MIS, EFOM, MARKAL, GOULDER, GEMINI, WARM, IIAM). A climatic submodel, which features an analysis of the climate change issue, makes only sense in long-horizoned models. This has been the case in RICE, MERGE, CETA and PERSEUS-GWI. The climatic submodel provides the models with capability to compute atmospheric concentrations of relevant greenhouse gases which, in turn, allows estimating potential changes in the global mean surface temperature. The climatic submodels of the integrated models mentioned above are very similar in structure. The Wigley Carbon Cycle Model (Wigley et al., 1996) can be given as an example of a climatic model.

The global dimension of climate change has lead to the incorporation of a global perspective in integrated energy models addressing this environmental problem. A look at Table 2.1 indicates that although more than half of the surveyed models are designed for national analyses (MIS, DREAM, MARKAL MEEET, MULTI, PESTES, JW, WARM, GOULDER, GEMINI, EFOM-ENV, PERSEUS-GWI), a regional representation combining neighbouring countries into regions is incorporated in the rest (MERGE, GLOBAL2100, CETA, IIAM, MARKAL RICE, ICF, ERB, MOBI-DK, MRMM). It is also possible to undertake minor modifications and apply a model in national as well as international analyses as has been done with MARKAL. Some regional models have been used to introduce a trade of emission certificates. The studies of Harrison et al. (1997), Manne et al.

(1995), Böhringer et al. (1998) and Nordhaus et al. (1996) provide examples of such studies performed with the models IIAM, MERGE, MOBI-DK and RICE respectively. The national model MULTI sets a market for pollution permits as well by reducing the idea of certificate trade to the individual firm level.

It should be noted that various models described above are closely linked to each other. So is MRMM the economy integrated multi-regional form of MARKAL; GLOBAL2100 is integrated with a climate and a damage assessment submodel to obtain MERGE; and PERSEUS-GWI is obtained by integrating greenhouse gas emitting sectors of EFOM-ENV with a climate submodel.

2.2.1. Energy Sector Optimisation Models

'Energy sector optimisation' models are simple linear models that minimise the total discounted energy cost subject to given demands and emission constraints. No economic effects outside the energy sector are considered in this category of linear programming models. In other words, the market shares for the various energy forms and technologies are determined by the minimisation of the present value of cost of meeting the various energy service demands specified for the model. The energy system is represented through an energy network where energy flows occur from a set of n supply nodes to m demand nodes. Energy costs and pollutant emissions are identified for a unit of energy passing over each of the n time m possible paths. For a given path j, a resource r_i is converted to intermediate energy form x_j at an efficiency $e_{i,j}$. In turn, the intermediate energy form is used to satisfy demand D_k at an efficiency $\eta_{k,j}$. Emissions are accounted via an emission factor f_j per unit of intermediate energy form and are restricted by an upper bound u. Such a model can be formulated in general form as

$$
\begin{aligned}
&\textit{Minimise} \ \textstyle\sum_j c_j x_j \\
&\textit{Subject to} \ \textstyle\sum_j (1/e_{i,j})\, x_j \leq r_i \qquad i = 1,\ldots,n \\
&\qquad\qquad\quad \textstyle\sum_j \eta_{k,j}\, x_j = D_k \qquad k = 1,\ldots,m \\
&\qquad\qquad\quad \textstyle\sum_j f_j\, x_j \leq u
\end{aligned}
$$

where c is the cost per unit energy.

MARKAL (Hollins, 1995), MRMM (Büeler, 1997), EFOM (Lueth et al., 1997) and PERSEUS-GWI (Ardone et al., 1996) are examples falling into this category.

2.2.2. Energy Sector Equilibrium Models

'Energy sector equilibrium' models are founded on microeconomic theory, i.e. they are based on agents' preference maximising behaviours. Demands are accordingly not exogenous but there is an additional demand side of the model on which demands are specified as a function of prices. In these models, energy prices adjust to balance supply and demand for the various primary, secondary and end-use energy forms, resulting in equilibrium in each market. These models incorporate only energy-related sectors of the economy, assuming all others remain unchanged and hence they do not have explicit macroeconomic capability. Due to the partial economic representation, these models are also called partial equilibrium models. In these models, markets are usually assumed to be perfectly competitive. A general formulation of an energy sector equilibrium model is given below where $i = 1, \ldots, n$ is the index for fuels, $j = 1, \ldots, m$ indexes the consuming sectors including conversion activities, p_i is the price of fuel i and p stands for the vector of prices. The excess demand function is given by $e_i(p)$, i.e. if $S_i(p)$ is the supply of product i as a function of all fuel prices and $D_{i,j}(p)$ is the demand for product i in sector j as a function of all fuel prices, then $e_i(p) = \sum_j D_{i,j}(p) - S_i(p)$. The analytical model is formulated as

$$\begin{aligned} &\text{Find } p = (p_1, \ldots, p_n) \\ &\text{Subject to } \; e_1(p) = 0 \\ &\qquad\qquad\quad \vdots \\ &\qquad\qquad\quad e_n(p) = 0 \end{aligned}$$

GEMINI (Cohan et al., 1994), ERB (Edmonds et al., 1994), ICF (William, 1994) and WATEMS-GDL (Chung et al., 1997) are examples falling into this category. These models allow looking in depth at the effects on fuel and technology market shares of a variety of assumptions about technology availabilities and environmental policies.

2.2.3. Aggregate Economic Equilibrium Models

Models that fall into the class of aggregate economic equilibrium compute GDP from an aggregate production function and allow more detail in the energy sector. Energy-economy interactions are represented via energy demand and cost relations similar to the ETA-MACRO model (Manne, 1977) which is an established proto-type in this category. The approach in ETA-MACRO maximises an economy-wide utility function under a one-sector economic growth model that uses energy inputs together with value added to produce output. Letting U denote utility and Y, C, I, NX, EC, ATC, E stand for gross production, consumption, investment, net exports, energy costs, abatement technology costs and energy aggregates respectively, such a model can be written in environment-integrated general form as follows where $[t]$, $[b]$, $[a]$ and $[z]$ denote the technology vector, the energy cost vector, the abatement technology cost vector and the energy activity vector respectively. $[e]$ is the vector of activity-dependent emission factors and u is an upper bound on emissions.

$$\begin{aligned}
&\textit{Maximise} && U = u(C) \\
&\textit{Subject to} && Y = f(K,L,E) \\
& && GDP = C + I + NX \\
& && Y = GDP + EC + ATC \\
& && E = [t]\,[z] \\
& && EC = [b]\,[z] \\
& && ATC = [a]\,[z] \\
& && [e]\,[z] \leq u
\end{aligned}$$

The objective is the maximisation of utility, which is usually the discounted sum of consumption. The first constraint comprises a production function with energy inputs in addition to primary factors. The second constraint is a conventional macroeconomic balance equation. The third equation defines gross production as the sum of the gross domestic product, energy cost and abatement technology cost. It is should be mentioned that the addition of energy and abatement technology costs to GDP involves double counting since GDP already includes those payments. That is, although C and I include energy components, the energy cost is explicitly accounted for in a separate component. However, the effect of double counting is in a way penalised by the inclusion of energy as a factor of production. Energy is treated explicitly as an additional factor in production and hence energy costs enter indirectly into gross output. Although this approach is not fully satisfactory from an economic point of view, it provides a fairly well representation of the two-way linkage between the energy sector and the rest of the economy. This approach permits ETA-MACRO to explore the interaction of macroeconomic issues with energy policies. The fourth, fifth and sixth constraints establish energy demand, energy cost and abatement cost relations respectively. The last constraint restricts total pollutant emissions by an upper bound u.

GLOBAL 2100 (Manne et al., 1994), CETA (Peck et al., 1994), MERGE (Manne et al., 1995), MIS (Kuckshinrichs et al., 1996), RICE (Nordhaus et al., 1997) and IIAM (Harrison et al., 1997) are examples of recent models with environmental integration that can be grouped in this class. These models are formulated as nonlinear optimisation problems. They specify markets for non-electric and electric energy in which a variety of energy technologies and fuels compete for market share. Due to the detailed representation of energy supply technologies, these models enable to study how policy cost is affected by different assumptions about costs and availabilities of various energy supply technologies. Moreover, they allow for a more detailed representation of energy-related pollutant emissions.

2.2.4. Disaggregate Economic Equilibrium Models

'Disaggregate economic equilibrium' models are of the general equilibrium type. They are based on microeconomic foundations similar to the above described 'energy sector equilibrium' models but have explicit macroeconomic capability as well. That is, they represent the involved agents as reacting to prices that equilibrate supply and demand in each market and at the same time contain all sectors of the economy featuring a detailed economic representation. These models differentiate between various sectors of the economy and simulate a market equilibrium for all goods and services. Due to the detailed sectoral representation in these models including a government sector and the microeconomic foundations, these models usually contain various taxes.

A general equilibrium model incorporating an energy tax features five commodities: the two primary factors labour *(L)* and capital *(K)*, one public good *(G)* one consumption good with C and Y as quantities consumed and produced, and an energy aggregate *(E)* which is used as a consumption good in quantity E_c as well as an intermediate factor in the production of Y (in quantity E_y). On the consumer side of the model, there is a representative household with total time endowment $\overline{F}$ and capital endowment $\overline{K}$ whose utility U is an aggregate of the consumed goods and leisure $(\overline{F}-L)$, i.e.

$$U = u(C, E_c, \overline{F}-L, G) \quad .$$

On the production side of the economy, all three commodities are produced via production functions

$$E = f_E(K_e, L_e)$$

$$G = f_G(K_g, L_g)$$

$$Y = f_Y(K_y, L_y)$$

A competitive market equilibrium is achieved via three types of general equilibrium conditions that complete the rest of the MCP formulation:

a) market clearing conditions which say that the use of goods or factors is equal to the supply:

$$C = Y$$

$$E = E_c + E_y$$

$$\overline{K} = K_e + K_g + K_y$$

$$L = L_e + L_g + L_y$$

b) the budget constraints of all agents in the economy:

- the representative consumer who spends the income from the supply of his labour and capital endowment on the consumption of goods:

$$p_c C + p_g G + p_e (1 + t_{ec}) E_c = wL + r\overline{K}$$

where w and r denote the factor prices of labour and capital and p_c, p_g and p_e denote the prices of the consumption good, public good and energy aggregates respectively; t_{ec} is the rate of tax on the use of energy in the household sector.

- the producers who receive the revenue from selling their goods and use it to finance their cost of production:

$$p_e E = w L_e + r K_e$$

$$p_g G = w L_g + r K_g$$

$$p_c C = w L_c + r K_c + p_e(1 + t_{ey}) E_y$$

where t_{ey} is the rate of tax on the use of energy as an input. The budget constraints for the producers are also known as zero-profit conditions in economic theory.

- the government who spends the tax revenue it receives on the provision of a public good:

$$p_g\, G = p_e\ t_{ec}\, E_c + p_e\, t_{ey}\, E_y$$

c) the first-order conditions

$$\frac{w}{r} = \frac{\partial f_E / \partial L_e}{\partial f_E / \partial K_e} = \frac{\partial f_G / \partial L_g}{\partial f_G / \partial K_g} = \frac{\partial f_Y / \partial L_y}{\partial f_Y / \partial K_y}$$

$$\frac{p_e}{p_y} = \frac{\partial u / \partial E_c}{\partial u / \partial C}(1+t_{ec})^{-1} = \frac{\partial f_Y}{\partial E_y}(1+t_{ey})^{-1}$$

$$\frac{w}{p_y} = \frac{\partial u / \partial(\bar{F}-L)}{\partial u / \partial C} = \frac{\partial f_Y}{\partial L_y}$$

$$\frac{p_e}{w} = \frac{\partial f_Y / \partial E_y}{\partial f_Y / \partial L_y}(1+t_{ey})^{-1} = \frac{1}{\partial f_E / \partial L_e}$$

MOBI-DK (Böhringer et al., 1998), GOULDER (Goulder, 1994), PESTES (Beaumais et al., 1995), JW (Jorgenson et al., 1994), MULTI (Nagurney et al., 1997), WARM (Carraro et al., 1997) and DREAM (Vennemo, 1995) are some examples falling into this category. MOBI-DK, GOULDER and JW have been used for energy tax analyses. The JW model has also been combined with a distribution model by Schillo et al. (1994) to analyse the distributional impacts of a carbon tax on different classes of households.

2.3. Original Features of Selected Models

Having elaborated the fundamental structure of models, some are scrutinised more closely in this section to highlight original features. That is, apart from major characteristics, some models have originalities in their formulation which distinguishes them with respect to some particular feature from other models of the same category. For example MERGE has a specific way to value damages caused by pollution and DREAM defines feedback links which relate such damages to productivity. Similar to DREAM, WARM endogenises technical progress via environmental feedback links. Productivity is also endogenised in JW, although not by environmental feedback links. The model GEMINI has no economic detail to endogenise productivity growth but it endogenises energy efficiency improvements. Other original features are identified as the 'capital adjustment dynamics' formulation in GOULDER, the 'time-lag' representation in WATEMS-GDL, the 'multi-stage budgeting' of MOBI-DK and the 'trade substitution' representation of IIAM. These features are explored in the following.

MERGE is an 'aggregate economic equilibrium' model that maximises the discounted utility of consumption subject to macroeconomic balance equations under a one-sector economic representation. It allocates aggregate economic output (Y) between payments for energy (EC), consumption (C) and investment (I), i.e.

$$Y = C + I + EC$$

and assumes that gross output depends upon four inputs: K, L, E, N – capital, labour, electric and nonelectric energy. Accordingly, the production function (f) is of the form

$$Y = f(K, L, E, N)$$

A climatic submodel is integrated in MERGE that estimates the effect of pollutant emissions on the global mean surface temperature via computing atmospheric pollutant concentrations. Temperature change is chosen as an indicator of ecological loss due to the well-known potential danger of global warming caused by greenhouse gas emissions. The output of the climatic submodel, the change in temperature, is used as an input into a damage assessment submodel. Typical damage assessment submodels assess the damages via a single damage function. The damage submodel in MERGE on the other hand divides potential damages of the temperature change into two categories: market and non-market. Market damages are defined to reflect categories that can be valued and are included in conventionally measured national income; like damages caused by natural disasters, or impacts on agriculture or impacts on tourism etc. Market damages (D) are specified as a function of temperature change (ΔT) and GDP:

$$D = d(\Delta T, GDP) \ .$$

The explicit recognition and treatment of nonmarket damages on the other hand reflects an original feature of this model. Nonmarket damages are defined as damages that cannot be readily valued; like damages on biodiversity, on human well-being, on environmental quality etc. These are valued in terms of willingness to pay; i.e. a specification of the form

$$WTP = w(\Delta T, GDP)$$

has been used where WTP stands for the willingness to pay to avoid ecological damages. An s-shaped function has been assumed for the relationship between willingness to pay and per capita income such that lower income regions place a lower value on ecological losses than higher income regions.

GOULDER is an 'disaggregate economic equilibrium' model that divides production into 13 industries (five of which are energy industries). Output in each industry (Y) is produced using inputs of labour (L), capital (K), an energy composite (E) and a materials composite (M). The distinguishing feature of GOULDER is its special attention to capital adjustment dynamics. The model is formulated such that output of each industry accounts for the notion that installing new capital necessitates a loss of current output as existing inputs that otherwise would be used to produce output are diverted to install the new capital. This is reflected in the production representation below where I denotes investment, ϕ stands for the adjustment cost function, and $\phi(I/K)\ I$ represents capital adjustment costs. The nested production structure of the model is summarised as follows

$$Y = f(g(L,K),\ h(E,M)) - \phi(I/K)\ I$$

$$E = E(E_1,\ \dots,\ E_5)$$

$$M = M(M_1,\ \dots,\ M_7)$$

$$E_i = E_i\ (ED_i,\ EF_i) \qquad i = 1,\ \dots,5$$

$$M_i = M_i\ (MD_i,\ MF_i) \quad i = 1,\ \dots,7$$

where *ED* and *MD* are domestically produced parts of the industry goods whereas *EF* and *MF* are foreign made components. The nested production structure presented above shows that the energy composite is composed of the specific energy products of the five energy industries. Similarly, the materials composite is composed of the specific materials products of the seven non-energy industries. The energy and materials products are themselves composed of domestically produced and imported components. The model could be classified as a typical one in its category if the output of each industry would not account for capital adjustment costs but only include a classical production function.

The 'disaggregated economic equilibrium' model JW disaggregates production into 35 industrial sectors five of which are energy industries. The behaviour of each of the industries is derived from a hierarchical tier-structured logarithmic cost function. At the highest level, the cost of each industry's output *(Y)* is assumed to be a function of the prices of energy *(E)*, materials *(M)*, capital *(K)* and labour *(L)*. At the second level, the price of energy is taken as a function of prices of the five energy goods. Similarly, the price of materials is taken as a function of the prices of all other intermediate goods. The described structure is similar to the previously described GOULDER's one, so far it is actually quite a regular model in its class with the representation

$$Y = f(L, K, E, M)$$

$$E = E(E_1, \dots, E_5)$$

$$M = M(M_1, \dots, M_{30})$$

The distinguishing unusual future of JW is that productivity growth is determined endogenously. Other models of the same kind take productivity growth to be exogenous, however JW models productivity growth as an endogenous function of relative prices; i.e. productivity growth (φ) in each industry is determined endogenously as a function of input prices (p_i)

$$\varphi = f(p_1, \dots, p_{35})$$

Accordingly, each industry's productivity growth can be biased toward some inputs and away from others.

GEMINI is an 'energy sector equilibrium' model that models an extensive energy system and includes great technology detail. The distinguishing characteristic of GEMINI is that it specifies various components of efficiency improvements in an endogenous formulation. Efficiency improvements are usually incorporated into such models via an exogenous 'autonomous energy efficiency improvement (AEEI)' parameter which is meant to reflect all changes in the consumption of energy per unit of economic output except those induced by changes in energy prices. In GEMINI however, many of the components of AEEI are determined endogenously. The represented components of efficiency improvements are:

- gradual improvements in existing electric generation and end-use technologies
- new technologies
- improvements in building thermal integrity
- improvements in electricity generation efficiency

All of these components are defined to have both autonomous and market-driven components; the actual change in efficiency in a given market, end-use or sector depends accordingly on the market interactions of competing technologies and fuels, on capital stock changes and on other factors.

WATEMS-GDL is an 'energy sector equilibrium' model designed for the assessment of emission control policies. Its distinguishing feature is to incorporate a time lagged effect in the response of consumers to prices, i.e. the effect of past prices on current demands. Accordingly, demand is represented not only as a function of current prices but also previous time periods' prices. That is, demand is modelled in the form $Q_t = f_t(p_1, p_2, \dots, p_t)$ where t represents the time period; Q_t is the vector of demands and p_t the vector of prices in period t. In other words, the demand function $f_t(\,)$ in period t relates the demand in period t to all previous periods' prices. More specifically, the model employs the following structure where A_t is a vector of constants in period t, E is a matrix of the lag elasticities and B is a matrix of short-run price elasticities.

$$\begin{pmatrix} Q_1 \\ \vdots \\ Q_t \\ \vdots \\ Q_T \end{pmatrix} = \begin{pmatrix} A_1 \\ \vdots \\ A_t \\ \vdots \\ A_T \end{pmatrix} - \begin{pmatrix} B & & & \\ \vdots & \ddots & & 0 \\ E_{t-1}B & & & \\ & & B & \\ E_{T-1}B & E_{T-2}B & & B \end{pmatrix} \begin{pmatrix} P_1 \\ \vdots \\ P_t \\ \vdots \\ P_T \end{pmatrix}$$

The model WARM is an example of an 'disaggregate economic equilibrium' model. Its modelling strategy focuses on agents' behaviour, however the model is different from the typical 'disaggregate economic equilibrium' models since it exploits econometric techniques that allow the specification of structural parameters of the estimated behavioural relationships. It is argued that the econometric estimation allows to deviate from the parameterisations of the behavioural relationships placed by calibration on general equilibrium models and enables a more explicit description of the economic mechanism through which economic variables affect technical progress. Another essential originality in WARM is the decomposition of the capital stock into environment-friendly (k_e) and polluting (k_p) parts. Using the decomposed formulation, WARM endogenises technical progress; i.e. the overall capital stock is defined as $k_0 = k_e + k_p$ implying an overall growth rate $g_0 = g_p + (g_e - g_p)(k_e/k_0)$. The dynamics of the polluting component of the capital stock is defined in the form $g_p = h(W,v)$ where v is a stochastic error term and W is a set of explanatory variables including R&D

spending, output demand, factor prices and the number of imported patents. According to this definition, the growth rate of the polluting stock decreases in time as a result of domestic research & development activities and imported patents. Thus, over time, technical change occurs such that an increasing amount of environment-friendly capital is used. In other words technical change, defined by the ratio k_e/k_p, is interpreted as an indicator of the environmental quality of the capital stock and affects all sectors of the economy; it provides the economy-environment link of the model.

The particular distinguishing feature of the 'disaggregate economic equilibrium' model DREAM is its twoway link between the environment and the economy. DREAM incorporates feedback links from environmental quality to labour productivity and capital depreciation; i.e. a health induced productivity index h and a capital depreciation rate δ have been defined such that both depend on the level of pollution. The forms $h = h(E)$ and $\delta = \delta(E)$ have been defined incorporating the notion that h and δ are indirectly functions of the level of energy consumption E. The functions have been specified in relation to the assumed fraction of emissions that cause health damage. In other words, the model accounts for the two environment-economy feedback links:

1) pollutant emissions cause health problems which decrease labour productivity
2) pollutant emissions contribute to corrosion which increases capital depreciation.

The 'aggregate economic equilibrium' model IIAM represents substitution in trade by differentiating products for the domestic and export markets. Typically models distinguish imported and domestically produced parts of goods, however IIAM distinguishes exported parts. The model disaggregates domestic production into two components: domestically used and exported parts. A typical production function is employed in which inputs of labour (L), capital (K) and energy (E) are combined to produce output (Y)

$$Y=f(K, L, E)\ .$$

The output is then allocated so as to differentiate the production for domestic (D) and export markets (X):

$$Y=g(D,X)$$

International energy markets are considered explicitly with global market clearing conditions of the form $\sum_r X_{rt}^f = \sum_r M_{rt}^f$ where M stands for imports; f, r and t denote the fuel type, region and time period respectively.

MOBI-DK, a ‘disaggregate economic equilibrium’ model with 27 sectors, allows consumer decision-making to occur in the form of multi-stage budgeting. That is, at the top level the consumer trades off a composite bundle of consumer goods (C) with leisure (l) within a utility function $u(\ )$ to achieve a certain level of utility (U), at the second level goods (Y_i) from the 27 sectors compete with each other and in the third stage the consumer decides how much to spend on domestic (YD_i) or imported goods (YM_i) in each sector i :

$$U = u(C, l)$$

$$u(C) = u(Y_1, \ldots, Y_{27})$$

$$u(Y_i) = u(YD_i, YF_i)$$

Accordingly, the nested structure that typically arises in production in these kind of models, is differently formulated in MOBI-DK to describe a nested utility structure in order to allow multi-stage budgeting decisions of the consumer.

2.4. Models Involving Environmental Taxation

Many environmental economists working on models within the framework of neo-classical theory conceive environmental problems as cases of market failure (e.g. Baumol, 1972; Hoel, 1998; O'Connor, 1999). In energy models, resource constraints lead to technological improvements and substitution by other fuels as scarcity increases. In a similar fashion, the atmosphere can be regarded as a natural resource which is slowly depleted by the emissions of gaseous pollutants. However, environmental resources have no price in the market place and thus the control mechanism does not work. Usually, other mechanisms such as taxes, tradeable emission permits or other rules that will ration demand to the necessary levels are substituted to correct for the market failure. From the whole set of policy instruments for environmental management, taxation enables the most easy and effective delineation within a national perspective as various scientists argue (Farrow, 1999; Hoel, 1998; Nellor, 1997).

The choice of the appropriate instrument to attain environmental goals is of considerable political relevance. Quotas, subsidies and direct controls currently dominate in practice as economic instruments for pollution control, however environment-related taxes are increasingly being used in OECD countries. In more and more countries, 'green tax reforms' are implemented or contemplated. For instance, the Netherlands has cancelled most environment-related charges (compulsory requited payments to either government or to bodies outside government) with pollution abatement financing purposes and replaced them by taxes paid into the general government budget. In 1998, France started a progressive transformation of earmarked charges into fiscal taxes paid to the central government budget. The revenues from environmental taxes (based on energy products, transport equipment and services, as well as emissions into air and water, ozone depleting substances, water pollution sources, waste management and noise) in 20 countries for which data is available amounted to an average of 2.5% of GDP in 1995 (OECD, 1999). Altogether, taxes on petroleum and products, and on the sale or use of motor vehicles generated more than 90% of all the pollution control related tax revenue in the 20 countries in 1995.

Taxes for air quality management in the form of emission or energy taxes in special are undergoing a significant evolution in the context of an integration between tax and environmental policies. Over the last decade, various countries have restructured existing taxes on energy products to include an environmental component. A pollution tax on energy products has for example been introduced in

Denmark, Finland, Norway, Sweden, the Netherlands, Italy and the UK. A tax directly on pollutant emissions is not being applied yet, especially due to problems in monitoring emissions, however it is in the phase of development in various developed countries. In Switzerland for example a legislation proposal which foresees the introduction of a CO_2 emission tax by year 2004 has already been presented to the Parliament in May 1999; it will be discussed during the year 2000 and is likely to be accepted according to the Swiss press.

The Commission of the European Communities has suggested in an Information Note on May 27th, 1992 (see Nellor, 1997) that environmental taxes be used to replace taxes on labour because environment taxes will impose lower social costs boosting economic activity and promoting employment. Tax incentives have also been suggested by the Intergovernmental Panel on Climate Change (Watson et al., 1996) as a market-based program to encourage continued innovation in energy-efficient and low GHG-emitting processes. The recently agreed-upon Kyoto Protocol (1997) strives to have parties implement policies and measures to reduce their GHG emissions by at least 5% below 1990 levels in the commitment period 2008 to 2012. The difficulty lies in the fact that it is not easy to determine an appropriate tax policy and to measure its impacts. This requires consistent and efficient modelling as well as difficult value judgements.

Stern et al. (1973) have constructed a static input-output (materials-process-product) model to assess some of the steady-state consequences of various pollution abatement strategies on an industry. Environmental taxes such as effluent tax, waste energy tax and inefficient energy usage tax are incorporated to increase the related input prices and shadow sales prices for the final products are calculated under the assumption of the imposed taxes. This shadow price, whether it is higher or lower than the actual market price, is then used to adjust prices.

Nellor (1997) has discussed implications of environmental taxes on the public finances and the macroeconomy. He finds that environment taxes will impose a greater excess burden and are less efficient than alternative taxes such as broad-based consumption taxes in promoting various nonenvironmental policy objectives like output and employment. He concludes accordingly that environment taxes should be targeted to environmental goals where they may be the appropriate policy instrument, but should not be used to replace other taxes in expectance of lower social costs boosting economic activity and promoting employment.

Hoel (1998) has discussed uncertain abatement costs, non-convex abatement costs and the difficulties of emission measuring as three arguments against the use of environmental taxes as a key instrument of environmental policy. He has also discussed a fourth argument saying that environmental taxes give rise to an unnecessary cost increase in production and therefore lead to higher unemployment in economies with unemployment. However his analysis has provided no justification for this argument.

Various applied models incorporating environmental taxes exist and most are of the CGE-type. The models developed by Böhringer et al. (1997), Garbaccio et al. (1999), Harrison et al. (1997), Goulder (1994), Jorgenson et al. (1994), Edwards (1997), Roson et al. (1997), Pireddu et al. (1997) and Roe et al. (1996) fall into this category. The superiority of CGE models for tax policy analyses is because of their ability to consider 'double dividend' effects, i.e. the ability to consider effects of using revenues from an environmental tax to finance reductions in marginal rates of an existing distortionary tax (a tax which distorts the initial demand and supply decision and causes an excess burden due to the change in consumers' plus producers' surplus).

2.5. Problematic Issues

It is essential for integrated studies of environmental science, technology and policy problems to assess life quality as a trade-off between environmental deterioration and higher material standards of living. However, there is no agreed-upon procedure to quantify the effects of environmental degradation, caused for example by stratospheric ozone depletion or global warming, on the quality of life. These effects are usually in the form of ecological damages that can lead to natural disasters and affect biodiversity and human health. A number of scientific investigations have been carried out to provide estimates of the social benefits of air pollutant emission reductions (Hall et al., 1992; Nordhaus et al., 1996; Hope et al, 1996; Krupnick et al., 1991; Zaim, 1997; Manne et al., 1995; Peck et al., 1994) based on various damage function forms. However, not only a great deal of uncertainty exists about the impact of air pollutant emissions on the climatic system, but also highly subjective assumptions are required for quantifying the impacts of an induced climatic change. It is basically for these reasons that there are great variations among results of studies attempting to value the social costs of CO_2 emissions to the atmosphere, e.g. estimates of the marginal impact of an extra tonne of carbon emitted into the atmosphere lie in the range of US \$4 to US \$270 per tonne of carbon (Hope et al., 1996).

In order to value the impact of climate change, various damage functions are appended into the integrated assessment models. The simulation models PAGE (Plambeck et al., 1997) and INTERA (Hope et al., 1996) can be given as examples of two different approaches attempting to value the impact of climate change. These models differ from one another in the way uncertainty is handled. PAGE relies on subjective probabilities and expresses uncertainty inputs as a triangular probability distribution which is meant to represent the degree of belief of the person using the model about the values that the parameter can take. By contrast, INTERA employs a nested set method and assumes that any value in a given uncertainty range is just as likely as any other. Assumptions and assertions concerning adaptation, timing of the pulse of emissions and various model parameters constitute sources of methodological differences between the two models. Damage functions have been integrated into RICE, MERGE and CETA in order to value the impact of climate change. However, the integrated damage submodels are all structurally very different and provide highly differing results as is the case with PAGE and INTERA. Moreover it should be noted that, in spite of the integrated damage valuation, the models do not incorporate any environmental feedback effects back to the economy in their representation. A problematic issue in damage valuation is that it necessitates to value human health. Dose-response functions provided by epidemiological studies as e.g. proposed by Zaim (1997) and Krupnick et al. (1991) are used to estimate health effects of air pollutant concentrations, but a monetary valuation of these effects is a highly value-laden subjective analysis. Similarly, damage estimation also requires a valuation of environmental quality. An environmental index has been proposed by Hope et al. (1990, 1992) to measure environmental quality by weighting various indicators through a comprehensive questionnaire. However, still the problem of a subjective valuation, upon which much disagreement exists, remains. Schneider (1997) gives a more detailed discussion of such issues. PERSEUS-GWI has been recognized as being the only model integrating a climatic submodel but no damage function. The analysis in PERSEUS-GWI concentrates on the level of emissions to reach the objective of stabilising the concentration of gases at a level where no dangerous climatic changes can be expected.

The concern in integrating environmental taxation into modelling studies produces information asymmetries and non-convexities. In tax analyses it is usually assumed that abatement costs and environmental costs are convex, but complete knowledge of the properties of the true aggregate abatement cost function is not known by the regulator at the time it sets an environmental tax. Moreover, there is often some degree of asymmetric information regarding the level of emissions from a source. These arguments point to complications which make the use of environmental taxes less straightforward than suggested in theory. Whatsoever, Hoel (1998) however shows that even in the presence of these arguments, environmental taxes may be better than most feasible alternatives as a means of controlling emissions.

Another problematic issue in constructing integrated energy policy models is the trade-off between what level of detail to include in the energy or economic representation. The discrepancy between the energy and economy frameworks is moderated by either defining as many energy related sectors as possible at the cost of an aggregate energy representation or by adopting a framework with a detailed energy sector but a one-sector economic representation. Neither approach is completely satisfactory especially when environmental effects must be considered. A detailed representation of energy activities implies a more detailed environmental submodel, but an aggregate economic framework limits the analysis since the environment is also affected to varying degrees by non-energy economic activity.

Further reading on problematic issues can be found in survey papers (Schneider, 1997; Stirling, 1997) that stress the importance of environment related issues and provide a detailed discussion of the strengths and weaknesses of integrated models for decision making.

CHAPTER III

ENERGY, ECONOMY AND ENVIRONMENT: AN OVERVIEW FOR TURKEY

Feedback effects between energy systems, economic development and environmental pollution need to be taken into consideration in developing national energy plans or environmental policies. This chapter starts with an overview of energy-economy-environmental interactions in general and continues with an elaboration of the Turkish situation in particular. The structure of the Turkish energy system, the country's economic balances as well as its environmental indicators are discussed.

3.1. A General Overview of Energy-Economy-Environmental Interactions

The emission of harmful pollutants depends mainly on the technological structure of a country's energy system, on the level and composition of primary energy consumption and on the composition and sectoral structure of final energy demand. The energy sector as a main source of pollution constitutes on the other hand an important part of the economic infrastructure of a country; production processes rely to a large extent on the use of energy. As a result, there are mutual interactions between the composition and structure of a country's energy system, its economic development and its environmental quality. The depletion rates of energy resources and its relation to output, the resource build-up through capital investments, the removal of pollution via clean-up procedures and welfare effects of pollutant activities are only some indicators of the complex interactions. Some examples demonstrating these interactions can be mentioned as follows:

- Sharp increases in energy prices can be a serious threat for economic development as experienced during the oil crisis of 1974. The cost of energy is a major item of the production cost in most sectors of the economy. A sharp increase in energy prices therefore creates an upward pressure on the price level of many goods and services. Energy price movements induce fuel substitution as well as changes in the technological structure of the energy system. The extent of price-induced substitution effects depends on the structure and flexibility of the economic system.

- Energy investments may add to large amounts altering economic balances. Depending on the financing methods, energy investments may have important debt implications contributing to the budget deficit and thus creating an inflationary effect.

- The balance of payments effect of energy imports and exports is another demonstrative aspect of energy-economy relationships. Especially in countries with a persisting current account deficit, energy imports may contribute to several long-term economic adjustment problems. Energy imports can inevitably force an increase in a country's foreign debt stock if foreign exchange is not readily available.

- The instalment of abatement technologies to reduce pollutant emissions changes relative costs of energy supply options. Accordingly, the basis of investment decisions changes with influence on long-term strategic energy plans.

- The choice of an instrument to reduce pollutant emissions, whether it is the introduction of environmental taxes, the establishment of emission certificates, or the setting of quotas, may affect economic balances. Depending on the market structure, various incentives may have differing effects on the economy, the energy mix and its technological structure.

It should be mentioned that the above discussion only attempts to emphasise some major aspects of energy-economy-environment interactions in order to underline the importance of a systemic perspective in energy and environmental planning. There are several other determinants as well as country-specific social, political and economic factors, which have influence on a country's energy system structure, its economic development and environmental quality.

3.2. The Turkish Energy System

Per capita energy consumption in Turkey is well below the European Union (EU) average. It is about half of the consumption of Portugal (where only commercial energy use has been 1,939 kg of oil equivalent per capita in 1995). However, with an annual average rate of 4.9% Turkey has shown the fastest primary energy growth during 1980-1995 in comparison to EU countries for which the average has been in the order of 2%. The per capita energy consumption in Turkey is also lower than in the ten Central and Eastern European countries Hungary, Poland, Estonia, the Czech Republic, Slovenia, Bulgaria, Romania, Latvia, Lithuania and Slovakia whose Accession Partnership for the European Union has been approved by the European Commission under 'Agenda 2000', the Commission's strategy for strengthening and widening the Union. Nevertheless it should be mentioned that per capita GNP in Turkey is much higher than in some of those countries. As of 1997 Bulgaria, Romania, Latvia and Lithuania have a GNP per capita of 1140, 1420, 2430 and 2230 dollars respectively whereas Turkey's per capita GNP is with 3130 dollars close to the economies of Poland, Estonia and Slovakia. Moreover, although Turkey's energy intensity (measured by GDP per unit of energy use) is with 1.8 $/kg as of 1995 lower than in EU member countries (where Portugal has the lowest value with 2.7 $/kg), it has a much more energy-intensive economy than the EU candidate countries listed under 'Agenda 2000' (whose energy intensities vary between 0.7 and 1.3 $/kg). Table 3.1 below provides some of Turkey's energy figures for recent years.

Table 3.1. Some Energy Indicators in Turkey
(Source: 1998 Energy Report, WEC Turkish National Committee)

	Unit	1990	1995	1996	1997	1998
Primary Energy Prod.	TTOE*	25,123	26,255	26,926	27,687	28,864
Final Energy Cons.	TTOE	41,256	49,512	54,190	56,922	56,153
Per Capita Cons.	KOE**	735	817	881	911	885
Electricity						
Installed Capacity	MW***	16,315	20,952	21,247	21,889	23,352
Thermal	MW	9,551	11,089	11,312	11,787	13,045
Hydro	MW	6,764	9,863	9,935	10,102	10,307
PRODUCTION	GWh****	57,543	86,247	94,862	103,296	111,022
Thermal	GWh	34,395	50,706	54,387	63,480	68,793
Hydro	GWh	23,148	35,541	40,475	39,816	42,229
Net Imports (Exports)	GWh	(731)	(696)	(73)	2221	3001
CONSUMPTION	GWh	46,820	67,394	74,157	81,885	87,705
Per Capita Cons.	KWh	1013	1411	1540	1688	1797

* Thousand Tons of Oil Equivalent
** Kilos of Oil Equivalent
*** Megawatt
**** Gigawatthour

The Turkish energy sector is dominated by State Economic Enterprises whose management and corporate decisions are under government influence. The Turkish Ministry of Energy and Natural Resources is currently studying ways to restructure the electricity and gas markets and increase privatisation.

3.2.1. Domestic Resources

As a reaction to the oil crisis in the late seventies, the focus of Turkish energy policies has been on the development of domestic resources in order to reduce the dependency on imported oil. Lignite coal and hydropower constitute presently the most important domestic energy resources in Turkey. A general overview is given in Table 3.2 which presents the domestic primary energy production pattern for recent years.

Table 3.2. Primary Energy Production (MTOE*)
(Source: 1998 Energy Report, WEC Turkish National Committee)

Year	Hardcoal	Lignite	Petroleum	Natural Gas
1980	2.195	3.738	2.447	0.021
1985	2.199	8.212	2.216	0.062
1990	2.080	9.524	3.903	0.193
1991	1.827	9.117	4.674	0.185
1995	1.319	10.735	3.692	0.166
1997	1.347	11.759	3.630	0.230
1998	1.143	12.792	3.385	0.514

* Million Tons of Oil Equivalent

3.2.1.1. Lignite

Lignite reserves can be found in various regions in Turkey, the most important being in Afşin-Elbistan, Muğla, Soma, Tunçbilek, Seyitömer, Konya, Beypazarı and Sivas. Total lignite reserves amount to approximately 7.3 billion tons in which the lion's share belongs to Afşin-Elbistan with a deposit of 3.3 billion tons. However, most of the Turkish lignites are of low quality. As can be seen from Table 3.3, lignites with a calorific value below 2,000 kcal/kg account for approximately 68% of all reserves. About 10% of the lignite resources are extracted by underground mining; the rest is produced in opencast mines. Because of the low quality, the lignites are mostly used for electricity generation. In 1997, 77% of the supplied lignite of 57.4 million tons has been used in power plants.

Table 3.3. Chemical Characteristics of Turkish Lignites
(Source: Turkish Coal Authority)

Region	Moisture (%)	Ash content (%)	Sulphur content (%)	Calorific value (kcal/kg)
DLI	43	18 - 20	0.6	1800
ADL	23 - 24	17 - 23	1.56	1090
OAL	24 - 26	28	1.8	1750
GLI	10 - 27	17 - 48	1.5 - 3.0	2170
MLI	30 - 40	17 - 20	0.5 - 1.2	2100
ELI	12 - 23	17 - 40	0.7 - 1.23	1550
GAL	3 - 6	36 - 43	0.5 - 1.0	4300
AEL	50 - 55	17 - 20	1.5 - 2.0	1050
CLI	15 - 22	10 - 18	1.0 - 2.0	2900
SLI	32 - 39	11 - 31	0.9 - 1.2	1600
GELI	21 - 43	8 - 40	1.0 - 2.0	1700
ILI	45 - 48	25 - 27	1.09	1050

3.2.1.2. Hardcoal

As of the end of 1998, total hardcoal reserves in Turkey amount to 1.1 billion tons. The domestic hardcoal is produced exclusively by underground mining in the Zonguldak region. The domestic production has been gradually decreased from a peak of more than 4.5 million tons in the seventies to 2.5 million tons in 1997. The decrease in domestic production is basically a political decision based on the high production costs due to the poor technological mining methods. The reduction is substituted by imported hardcoal.

3.2.1.3. Oil

As of the end of 1998, the Turkish crude oil recoverable reserves have been in the order of 43.7 million tons. In 1998, the Turkish Petroleum Corporation TPAO has produced 16,957,256 barrels (2,459,222 tons) of crude oil from its fields, and with this amount TPAO constituted 76% of the total crude oil production of Turkey. Currently, there are five refineries in Turkey with a joint annual crude oil processing capacity of about 32 million tons.

Turkey has been involved in international transportation since the seventies. Two Iraq-Turkey crude oil pipelines with a total capacity of 70.9 million tons per annum deliver at limited capacity (due to the UN embargo) Iraqi oil to the Ceyhan marine terminal at the Mediterranean cost of Turkey. An international agreement between Turkey, the Azerbaijani Republic and Georgia has been signed for implementation of the Bakü-Tiflis-Ceyhan oil pipeline project which will deliver Caspian oil to world markets at a rate of approximately 1 million barrels per day.

3.2.1.4. Natural Gas

Turkish gas reserves are restricted to a useful potential of 12.3 billion m^3 of which 2.9 billion m^3 have already been used. Accordingly, the domestic production is also quite limited; 565 million m^3 gas has been produced in 1998. Despite low domestic production, natural gas has been used in significant quantities since 1987 when initially 500 million m^3 of gas was imported from the Soviet Union. Accordingly, natural gas consumption has increased rapidly and has reached 10 billion m3/year in 1998. Official estimates are such that the share of natural gas in the total supply of primary energy will continue to increase from 13% (10 billion m3/year) in 1998 to 27%(54 billion m^3/year) in 2010. The Ministry of Energy and

Natural Resources estimates that at least 5 billion dollars will be required to construct new transmission systems to accomodate such volumes within the next 5-10 years and about 10 billion dollar may be necessary for new industrial and residential distribution networks.

A natural gas pipeline coming from the Russian Federation is currently transporting around 7 billion m^3/year since 1987 and various new pipelines are planned. The so-called 'Blue Stream Turkmenistan-Turkey-Europe' natural gas pipeline project for Implementing the Transcaspian Pipeline is the most important one among other potential pipeline-agreements, which will enable to transport natural gas from Iran, Iraq and Egypt.

3.2.1.5. Renewables

Solar energy production in year 1998 was about 0.1 MTOE, 76% of which has been used by the residential sector. Sun collectors are being widely used in the southwestern coastal zone of Turkey to obtain warm water, however the share of solar energy in total primary energy is apparently still neglectable.

There is a single geothermal power plant in Turkey, which has produced 85 Gwh of electrical energy in 1998. In the same year geothermal heat energy of 153 MTOE has been used in the heating of various buildings and greenhouses. Known geothermal potential is about 200 MW for electricity generation and 2250 MW for heating; 70% of this potential is located in the Marmara region.

3.2.2. Fuel Imports

More than half of Turkey's energy requirements are met by imports, 62% of the primary energy demand in 1998 has been met by imports and according to official forecasts this portion will rise to 75% in 2020. Petroleum, natural gas and hardcoal are the major imported fuels; the amounts imported are given in Table 3.4.

Table 3.4. Fuel Imports (MTOE*)
(Source: 1980,85,90,95,97, 98 Energy Reports, WEC Turkish National Committee)

Year	Hardcoal	Natural Gas	C.oil & Petroleum
1980	576	0	14,339
1985	1,624	0	17,574
1990	3,390	2,964	23,516
1995	3,624	6,242	28,527
1997	5,950	8,995	29,430
1998	7,422	9,312	30,286

* Million Tons of Oil Equivalent

As can be seen from the above table, imports of crude oil and petroleum account for about 66% of all fuel imports. Natural gas imports take a share of nearly 20% and hardcoal imports account for about 13%. Energy imports in future are expected to continue to include hardcoal, petroleum and natural gas. The Energy Demand Program of the Ministry of Energy and Natural Resources foresees a shift in the energy import policy towards hardcoal as indicated by official forecasts summarised in Table 3.5. Accordingly, in year 2020, it is expected that hardcoal will dominate imports with about 143 million tons corresponding to approximately 87 MTOE, petroleum will take second place with nearly 74 million tons corresponding to approximately 78 MTOE and natural gas will take the last place with about 78 million tons corresponding to approximately 71 MTOE. The expected shares in 2020 become 37%, 32.8% and 30.2% for hardcoal, petroleum and natural gas respectively.

Table 3.5. Official Energy Import Forecasts (Original units)
(Source: 1998 Energy Report, WEC Turkish National Committee)

Year	Hardcoal (Thousand Tons)	Natural Gas (10^6 m^3)	Oil (Thousand Tons)
2000	18,848	14,690	32,845
2005	24,226	46,203	36,976
2010	47,037	55,006	43,572
2015	84,843	63,229	61,208
2020	142,235	82,628	63,756

3.2.3. Electric Energy

Some electrical energy indicators by the end of 1998 are as follows:

- Hydraulic Capacity : 10 300 MW
- Thermal Capacity : 13 000 MW
- Total Installed Capacity: : 23 300 MW
- Total Generation : 111 Billion kWh
- Total Imports : 3 Billion kWh
- Total Electricity Consumption : 88 Billion kWh
- Per Capita Consumption : 1 797 kWh

Gross electricity production was about 111 billion kWh in 1998; the length of transmission lines was 40161 km. By the end of September 1999, total installed capacity for electricity generation has reached 25,760 MW. The development of electric energy production with respect to primary energy sources is shown in Table 3.6 below.

Table 3.6. Electric Energy Production according to Primary Energy Sources (Gwh*) (Source: 1998 Energy Report, WEC Turkish National Committee)

Year	Hardcoal	Lignite	Oil	Natural Gas	Hydro
1980	911.7	5,184.3	5,831.2	-	11,348.2
1985	710.3	14,317.5	7,082.0	58.2	12,044.9
1990	620.8	19,560.5	3,941.7	10,192.3	23,147.6
1995	2,232.1	25,814.8	5,772.0	16,579.3	35,540.9
1997	3,272.8	30,587.2	7,157.3	22,085.6	39,816.1
1998	2,980.9	32,706.6	7,923.3	24,837.5	42,229.0

* Gigawatthour

Industry and households have the lion's share and account for 77% of total electric energy use; official buildings and general enlightening cover about 8% and the remaining 15% is used for transportation and other miscellaneous purposes. No remarkable change in these percentages has been detected in recent years, e.g. the share of industry is 57% and 56% in 1991 and 1995 respectively and the share of households is 21% in both years.

Official estimates of electric energy demand are based on the MAED (Model for Analysis of the Energy Demand) model. A simulation model, which deals with energy demand forecasts, is utilised by the Ministry of Energy and Natural Resources as a submodule of MAED. Two other submodules, which are used for converting the yearly demand figures to hourly loads and to load duration curves, are utilised by the Turkish Electricity Generation Transmission Corporation. The latest official forecasts are such that total electricity consumption will reach

200 Twh in 2005, 290 Twh in 2010 and 547 Twh in 2020. The Ministry of Energy and Natural Resources estimates that, in order to satisfy this growing demand, it will be necessary to add to the system approximately 41,700 MW of capacity until the end of 2010 and a further 45,000 MW until the end of 2020. The total planned additional capacity for the period 1998-2002 is 3,904 MW with an expected incremental production amount of 20,297 Gwh.

A look at the sectoral distribution of electricity consumption, provided in Table 3.7, indicates in recent years a slight increase in the proportion of residential use and a slight decrease in the share of electricity manufacturing uses. The table shows that the share of transportation is constant whereas a slight increase in the share of agriculture. The per capita electricity consumption increased from 459 kwh in 1980 to 1,281 kwh in 1997. The latest information is such that in 1998 per capita electricity consumption has been 1764 kWh.

Table 3.7. Sectoral Distribution of Electricity Consumption (Gwh*)
(Source: 1998 Energy Report, WEC Turkish National Committee)

Year	Manufacturing	Residential	Agriculture	Transportation
1980	13,008 *(63.7%)*	7,081 *(34.8%)*	160 *(0.8%)*	149 *(0.7%)*
1985	19,608 *(66.0%)*	9,576 *(32.2%)*	311 *(1.0%)*	213 *(0.8%)*
1990	29,212 *(62.4%)*	16,688 *(35.6%)*	575 *(1.2%)*	345 *(0.8%)*
1995	38,007 *(56.4%)*	27,384 *(40.6%)*	1,513 *(2.2%)*	490 *(0.8%)*
1997	44,742 *(54.4%)*	34,794 *(42.3%)*	2,153 *(2.6%)*	611 *(0.7%)*

* Gigawatthour

3.2.4. Nuclear Energy

Presently there is no nuclear energy generation in Turkey. The Turkish Electric Generation and Transmission Corporation has recently started a nuclear program for the construction of a nuclear power plant with approximately 3,000 MW capacity at Akkuyu Bay on the Mediterranean coast. The plant is to use enriched uranium for nuclear power generation. Turkey has uranium reserves amounting to 9,192 tons in the Salihli-Köprübaşı region and in Yozgat-Sorgun. However, there is much debate and civil opposition to nuclear energy. Protests from Turkish and foreign environmental groups has led the government to postpone the final decision. Concerns about security measures, fear of nuclear leakage and the problem of radioactive waste disposal are the main arguments opponents put forward against nuclear energy. Civil protests against the planned nuclear plant have become more vocal as a result of the recent earthquakes in Turkey; the Ecemis seismic fault line is just 20 kilometres away from the proposed plant site. However, the Turkish nuclear energy body describes the site as suitable and the government has declared its determination to realise the project.

3.2.5. Nonelectric Energy

The demand for nonelectric energy may be in the form of primary energy, or, converted into useful energy, in the form of secondary energy, e.g. from fuel oil or gas to space heat in households. The sectoral nonelectric energy demand, decomposed into primary energy forms, is given in Table 3.8 below. It can be seen from the Table that in all sectors nonelectric energy use is dominated by petroleum products. The increase in natural gas in households in recent years is because of the municipalities' promoting activities in major western cities of Turkey to use natural gas instead of low-quality coal or fuel-oil for heating purposes in order to reduce air pollution. In parallel to the increase of residential natural gas consumption, the industrial use of natural gas has also increased. This increase in natural gas consumption is closely coupled with the construction of pipelines as explained in Section 3.2.1.4 in detail. As a result of the increased natural gas consumption, the nonelectric oil&gas/solids ratio has changed in favour of oil&gas to become a number in the order of 1.4 -1.5 in recent years whereas it was constantly about 1.1 in the eighties.

Table 3.8. Sectoral Breakdown of Nonelectric Energy Use (MTOE*)
(Source: 1980,85,90,95 and 97 Energy Reports, WEC Turkish National Committee)

		Hardcoal	Lignite	Oil	Natural Gas
Households	1980	0.117	1.674	2.349	0
	1985	0.262	2.751	2.219	0
	1990	0.778	2.164	2.995	0.045
	1995	0.801	1.910	4.039	0.904
	1997	0.783	2.008	3.709	2.238
Agriculture	1980	-	-	0.949	-
	1985	-	-	1.479	-
	1990	-	-	1.934	-
	1995	-	-	2.377	-
	1997	-	-	2.650	-
Transportation	1980	0.148	0.038	5.031	-
	1985	0.108	0.019	6.049	-
	1990	0.008	0.007	8.707	-
	1995	0.002	-	11.072	0.001
	1997	0.005	-	11.278	0.003
Industry	1980	0.357	1.046	4.055	0.021
	1985	0.591	1.649	3.968	0.046
	1990	0.890	2.538	5.586	0.740
	1995	1.176	1.769	6.055	2.036
	1997	2.352	2.029	5.962	2.732

* Million Tons of Oil Equivalent

3.3. The Turkish Economy

The post-1980 economic history of Turkey is characterised by various economic policy shifts as a result of political instability. However, basic policies did not deviate much from a structural adjustment towards liberalisation. Comprehensive economic and institutional reforms have been initiated covering privatisation, trade liberalisation as well as the liberalisation of financial markets. Table 3.9 presents some indicators for the Turkish economy. A look at the foreign trade figures indicates an increase in Turkish exports and imports growing at an average 11-13 % per year since 1983.

Table 3.9. Development of Some Economic Indicators in Turkey
(Source: SPO Main Economic Indicators February 1998)

	GDP $(10^6\ \$)$	Imports $(10^6\ \$)$	Exports $(10^6\ \$)$	Imp/GDP (%)	Exp/GDP (%)
1983	62,072	9,235	5,728	14.88	9.23
1984	60,349	10,757	7,134	17.82	11.82
1985	67,706	11,343	7,958	16.75	11.75
1986	76,307	11,105	7,457	14.55	9.77
1987	87,323	14,158	10,190	16.21	11.67
1988	90,955	14,335	11,662	15.76	12.82
1989	107,189	15,792	11,625	14.73	10.85
1990	150,735	22,302	12,959	14.80	8.60
1991	151,113	21,047	13,593	13.93	9.00
1992	159,181	22,871	14,715	14.37	9.24
1993	180,400	29,428	15,345	16.31	8.51
1994	130,231	23,270	18,106	17.87	13.90
1995	169,841	35,709	21,636	21.02	12.74
1996	182,063	42,734	23,123	23.47	12.70

The annual growth rate of GDP has been on the average 4.7 % per year since 1983. Expectations are such that it will continue to grow at an annual rate of 4-5%. The sectoral composition of GDP is shown in Table 3.10, there appears a clear tendency of GDP composition away from agriculture to more industrial-oriented activities. The rise in the industrial sector is dominated by manufacturing and energy industries. This is typical for a developing country in the transition process to an industrialised economy.

Table 3.10. Sectoral GDP Composition (%)
(Source: http://www.dpt.gov.tr/dptweb/esg/esgx.html)

	Agri-culture	Industry			Services				Other
		Mining	Manuf.	Energy	Constr.	Trade	Transp.	Public	Miscell.
1983	20.9	1.9	19.1	0.9	5.5	18.4	13.4	5.9	14
1984	21.2	1.8	18.1	1.2	5.4	19.2	13.5	5.1	14.5
1985	19.7	1.6	18.3	1.8	5.8	19.1	12.7	5.1	15.9
1986	19.5	1.6	22.2	1.6	6.9	18.3	11.7	4.7	13.5
1987	17.8	2.0	21.8	2.0	7.3	19.9	11.6	5.1	12.5
1988	17.3	1.8	23.0	2.2	7.7	19.9	11.8	4.9	11.4
1989	16.6	2.0	23.1	1.9	7.0	18.8	11.6	6.8	12.2
1990	17.5	1.6	22.0	2.0	6.3	19.1	11.8	8.3	11.4
1991	15.2	1.5	22.2	2.2	7.0	18.6	11.8	9.7	11.8
1992	15.0	1.4	21.6	2.6	6.8	18.5	12.2	10.2	11.7
1993	15.4	1.1	20.8	2.6	7.4	18.6	12.0	10.3	11.8
1994	15.5	1.4	22.1	2.9	6.8	19.7	13.3	8.9	9.4
1995	15.7	1.3	22.6	2.5	5.5	20.5	12.6	8.0	11.3
1996	16.9	1.2	21.1	2.8	5.8	20.5	13.1	8.4	10.2

Total investments in Turkey have amounted to 49.9 billion US dollars in 1998, 33% of which having been realised by the public sector. It can be seen from Table 3.12 that the lion's share in investments goes to the transport and housing sectors; e.g. in 1998 the transport sector receives 34.6% of public investments and the housing sector receives 36.8% of private investments. Energy investments are also considerably high; they hold with 17% the second rank among public investments and have been in the order of 3.3 billion US dollars in 1998. Table 3.11

indicates an increase in the share of energy investments in recent years. The Turkish Ministry of Energy and Natural Resources estimates that only the expansion of power generation capacity (based on official forecasts of 41,700 MW and 86,700 MW required additional capacities by the years 2010 and 2020 respectively) requires annual investments in the order of 4.5 billion US dollars. That is, total necessary investments for sufficient electricity generation up to year 2020 are estimated to sum up to approximately 100 billion US dollars including the investments to be made to increase transmission and distribution capacity.

Table 3.11. Investment Composition (%)
(Source: http://www.dpt.gov.tr/dptweb/esg/esgx.html)

Sectors	Public Investments			Private Investments		
	1996	1997	1998	1996	1997	1998
Agriculture	10,4	11,1	7,8	4,7	4,3	4,6
Mining	1,5	1,6	1,5	1,1	1,1	1,3
Manufacturing	4,0	2,5	2,8	26,2	22,9	22,4
Energy	12,8	12,4	17,1	1,8	4,0	3,2
Transport. & Commun.	34,4	34,8	34,6	17,4	21,6	19,7
Tourism	1,4	0,6	0,5	2,3	2,5	3,6
Housing	1,7	1,4	1,5	39,6	35,8	36,8
Education	9,4	12,4	10,6	1,1	1,1	0,8
Health	4,4	5,1	4,7	1,8	2,9	3,5
Other Services	20,0	18,2	19,0	4,0	3,8	4,0
Total	100,0	100,0	100,0	100,0	100,0	100,0

3.4. Environmental Issues

The production, transport and use of different sources of energy raise a number of important environmental issues, the most critical ones being pollution problems affecting ecosystems and threatening human health. Even the most efficient sources of energy have their cost, whether it is the pollutant emissions into the air, the slag left over from mines or the droughts and hydroecological changes caused by hydroelectric dams. The focus in this study is on emissions of gaseous pollutants into the air; a brief introduction follows.

3.4.1. Emissions of Gaseous Pollutants

In the case of a fossil fuel plant, the main environmental residuals under normal operating conditions consist of emissions of various gaseous pollutants, including sulphur dioxide (SO_2), nitrogen oxides (NO_x) and carbon dioxide (CO_2), with harmful environmental effects. The level and development of emissions are closely coupled to the composition of the primary energy consumption as well as the technological structure of the energy system. The composition and sectoral structure of the final energy demand is another important factor affecting emission levels.

Pollutant emissions are altering the natural balance of gases in the atmosphere. They lead primarily to climate change, cause acidic deposition and contribute to the depletion of the ozone layer affecting the ecosystems and endangering human health.

3.4.2. Air Pollutants in Turkey

In July 1995, Turkey signed an agreement with the World Bank for the preparation of a national environmental action plan financed by the Institutional Development Fund. In this context, various working groups have been formed and two years later a report (SPO, 1997) has been published concerning air pollution resulting from the energy sector in Turkey. The report foresees SO_2 and NO_x emissions in 2010 to reach levels of 4 and 1 million tons per year respectively. Emission standards for the two pollutants are defined by the Turkish Regulation on the Protection of Air Quality as shown in Table 3.12. A revision study on tightening the emission standards is going on according to officers from the Ministry of Environment, however the regulation from 1986 is officially still in use.

Table 3.12. Turkish Emission Standards (mg/m^3)
(Source: Turkish Republic Prime Ministry Environmental Directorate, 1986)

Pollutant	Plant type	Solid Fuels	Liquid Fuels	Gas
SO_2	New Plants with installed capacity < 300 MW	2000	1700	60*
	New Plants with installed capacity > 300 MW	1000	800	60
NO_x	New Plants with installed capacity < 50 MW	-	-	-
	New Plants with installed capacity > 50 MW	800	800	500
SO_2	Old Plants	3200	3200	-
NO_x	Old Plants with installed capacity < 50 MW			-
	Old Plants with installed capacity > 50 MW	1000	1000	500

The present level of pollutant emissions in comparison to most EU countries is moderate in Turkey. However, a closer integration of Turkey into the EU region will result in the need of harmonisation and adjustment of energy and emission control policies which is likely to result in the application of the emission control regulations of the European Union in Turkey. The Council of the European Union has adopted a Directive on ambient air quality assessment and management; defined standards for sulphur dioxide and nitrogen dioxide emissions as of November 1999. Table 3.13 shows these standards.

Table 3.13. European Emission Standards (mg/m^3)
(Source: http://europa.eu.int/eur-lex/de/com/pdf/1999/de_599PC0611.pdf)

Pollutant	Plant type	Solid Fuels	Liquid Fuels	Gas
SO_2	Plants with installed capacity 50 - 100 MW	850	850	35
	Plants with installed capacity 100 – 300 MW	850 → 200 (linear decrease)	850 → 200 (linear decrease)	35
	Plants with installed capacity > 300 MW	200	200	35
NO_x	Plants with installed capacity 50 - 100 MW	400	400	150
	Plants with installed capacity 100 – 300 MW	300	300	150
	Plants with installed capacity > 300 MW	200	200	100

In contrast to the Turkish Regulation for the Protection of Air Quality, the European Regulation for both, SO_2 and NO_x emissions, applies only for combustion plants with a capacity exceeding 50 MW and is valid for new plants only. The emissions of existing plants are restricted by global limits on their total annual emissions, which differ from country to country. The European standards are obviously much more stringent than the Turkish ones.

3.4.3. Abatement Technologies

Abatement technologies that are considered by the Turkish Electricity Generation and Transmission Corporation as feasible under Turkish conditions are the Wet Limestone and Wellmann Lord desulphurisation processes for sulphur and

SO_2 abatement and Primary Measures and Selective Catalytic Reduction for NO_x abatement. These technologies are briefly described as follows, their financial requirements are provided in Table 4.3 of the next chapter.

- *The Wet Limestone Process*: This is a nonregenerative flue gas desulphurisation process using lime and limestone as absorbent materials. The lime or limestone is used directly in the scrubber solution. The SO_2 removal efficiency of this process is about 95 % in general and it can be applied in combustion installations burning various fuels of different qualities, including lignite. This process is currently being applied at the lignite-fired power plants in Bandirma and Cayirhan.

- *The Wellmann-Lord Process*: This process has a complex technology. Sulphur dioxide is removed by absorption by an alkali (sodium, calcium, and/or magnesium) solution or char, charcoal, or alumina pellets. The resulting sulphur salt or concentrated sulphur adsorbed is then collected and the sulphur dioxide is regenerated in much higher concentrations, freeing the absorbing or adsorbing material for reuse. The concentrated sulphur dioxide gas is then either oxidised to sulphur trioxide and converted to the marketable by-product sulphuric acid or the sulphur dioxide gas is reduced to elemental sulphur. This process is applicable in lignite fired power plants; it may especially be economically competitive in power plants using high-sulphur lignite. The SO_2 reduction removal efficiency reaches 98%.

- *Primary Measures*: These include combustion modification and flue gas recirculation. Since the formation of NO_x is strongly temperature dependent, the NO_x emissions can be reduced by lowering the combustion temperature and by eliminating the hot spots in the furnace. The formation of nitrogen oxides can also be reduced by lowering the air-fuel ratio and/or by employing exhaust gas recirculation. These measures are applicable in all fossil-fueled power plants, and reach a NO_x reduction efficiency of 40%.

- *Selective Catalytic Reduction*: This denitrification process involves the injection of ammonia (NH_3) into the flue gas that passes through a catalyst bed in which the ammonia and nitrogen oxides react to form harmless nitrogen and water vapor. The Selective Catalytic Reduction technology achieves a removal efficiency of 88%.

CHAPTER IV

ENVEES: A SINGLE-SECTOR ENERGY-ECONOMY-ENVIRONMENTAL INTEGRATED ASSESSMENT MODEL

This chapter presents a one-sector energy-economy-environmental model, named ENVEES (Environment-Energy-Economy Single-Sector Model), that integrates environmental taxation as a policy instrument to control emissions. The environmental tax-incorporated basic model is presented first; it includes energy and emission taxes as alternative instruments to reduce pollutant emissions. Next, two different specifications of the basic model are stagewise developed: the fist one endogenises pollution abatement and the second endogenises environmental taxation.

4.1. Introduction

ENVEES is developed on the basis of the energy-economy-environmental interactions model MEEET (Arıkan et al., 1997) which is a combination of an energy-environmental model with a one-sector model of economic growth. MEEET has been developed as part of a project supported by the Scientific and Technical Research Council of Turkey (Arıkan et al., 1995). It is an ETA-MACRO (Manne, 1977) type model and is an extension of Güven's model (Güven, 1994), which also takes emission levels and costs into consideration. The ETA-MACRO model estimates two-way interdependence between the energy sector and the rest of the economy by combining an energy model with a one-sector model of economic growth. The approach used in ETA-MACRO distinguishes different energy forms as intermediate products contributing to the production of goods and services for final demand. The approach has been elaborated in section 2.2.3 in more detail. Güven's model uses the same approach but includes an explicit representation of foreign trade which makes it capable of capturing the interdependency between foreign exchange expenditures of energy and the rest of the economy.

4.2. General Description of the Model

The model specifies a nested constant elasticity of substitution (CES)-type production function to illustrate the production process in which capital, labor, intermediate goods and energy are inputs to economy-wide production. The link between the economy and energy submodels is established by energy demand and cost relations. Electric and nonelectric energy are supplied by the energy sector to the rest of the economy. The economy model is structured so that investments generate the stock of capital which, together with the inputs of energy, labor and intermediate goods imports, determines gross output. In turn, this output is allocated between consumption, investments and energy costs. Energy costs include the cost of pollution abatement determined in the environment submodel. The energy-environment link is established by energy activities which lead to pollutant emissions. Abatement technology alternatives, together with other measures such as fuel switching, energy conservation and efficiency improvements, enable to reduce pollutant emissions. MEEET has been extended to incorporate environmental charges such as energy or emission taxes as a policy measure for emission abatement. The installation of abatement technologies is accordingly encouraged by environmental taxation. Figure 4.1 provides an overview of the structure of ENVEES.

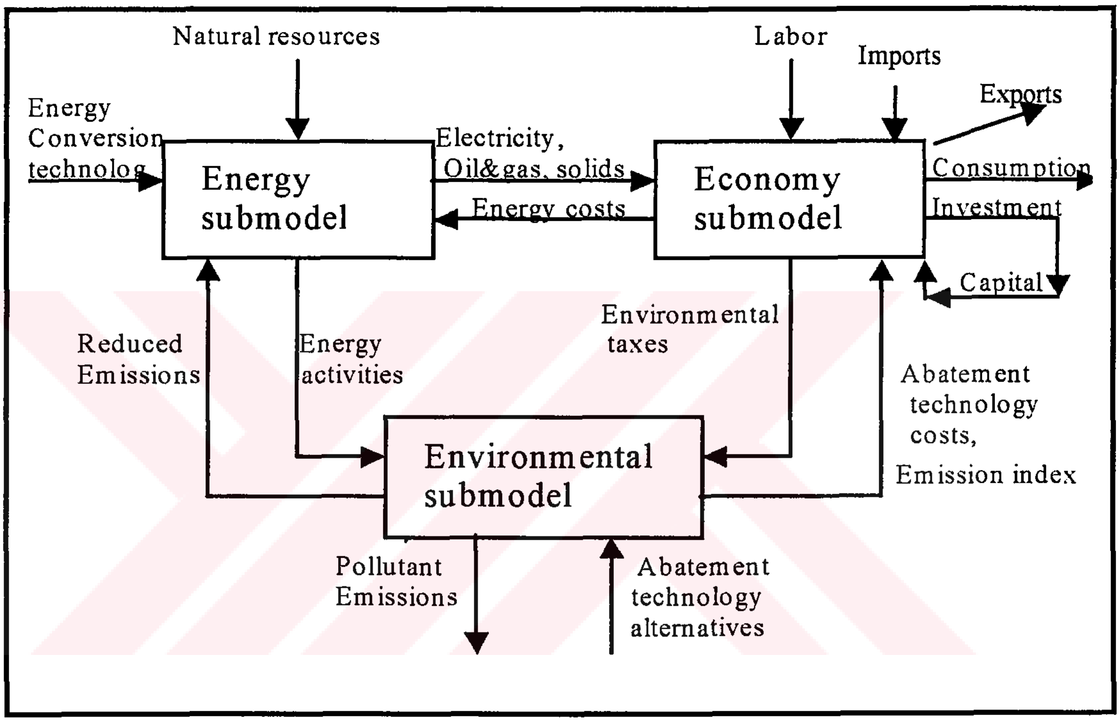

Figure 4.1. An Overview of ENVEES Model Interactions

Figure 4.2 illustrates the energy flow structure of the model. In the combined model, different energy chains are aggregated in several subsystems. Primary energy sources are included in the primary subsystems. The intermediate supply sectors represent the generation of electricity for industrial and residential applications, and the utilisation subsystems represent the conversion from final to useful energy. Pollutant emissions are computed at energy conversion and utilisation processes and possible abatement technologies are introduced.

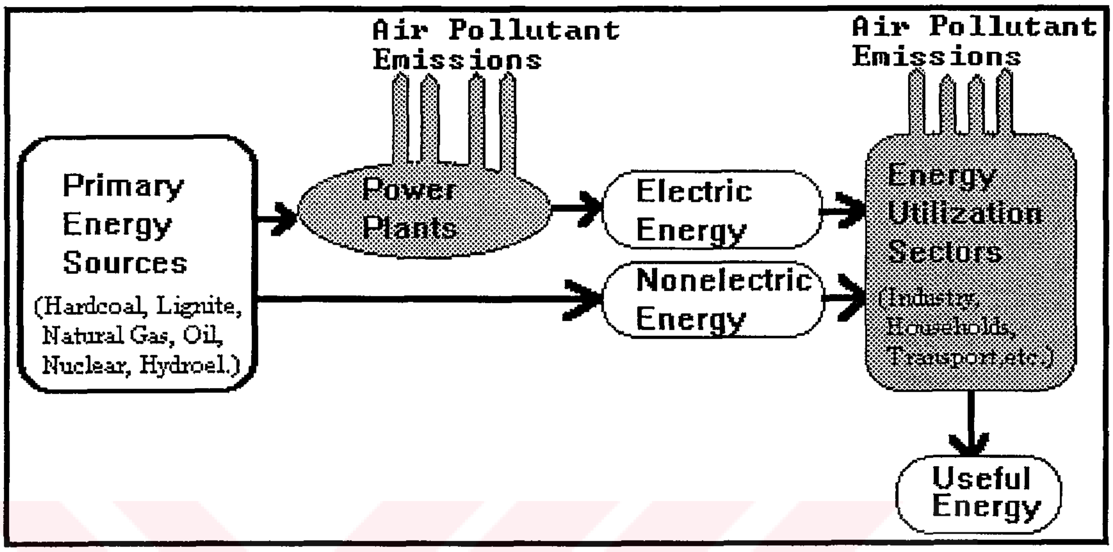

Figure 4.2. General Energy Flowsheet and Pollutant Emissions

The price-responsive structure of the model allows for price-induced energy conservation and substitution. The energy, the economy and the environmental submodels are linked together to produce equilibrium solutions that maximise utility over the planning horizon. The long-term view of the model permits a dynamic comparison of alternatives and provides a consistent framework for policy analysis.

4.2. Model Formulation: Principal Constraints and Original Features

The formulation presented in this section is in summary form and aims to provide a basic understanding of the model structure. The full constraint set of ENVEES is given in appendix A.

4.2.1. General Features of the Model

Production is defined by an economy-wide incremental putty-clay nested CES function. That is, substitution is allowed only among incremental factors of production (the malleable 'putty') assuming that surviving stocks (the rigid 'clay') remain unchanged. Capital stock has been disaggregated into a domestic component (KD_t) formed by domestically produced investment goods and a foreign component (KF_t) formed by imports. The model also recognizes imported nonenergy intermediates (INT_t) explicitly. These features were inherited from the original version of the model (i.e. Güven, 1994) which was first constructed when currency restrictions applied. Turkey's foreign exchange reserves and its ability to borrow foreign capital have meanwhile increased and foreign exchange is more easily available. Güven's treatment of imports, that is his explicit recognition of imported intermediates as a factor of production, his consideration of fuel imports and his distinguishing the capital stock into domestic and imported components, may appear less relevant today. But the original formulation has been preserved since the Turkish economy still relies on foreign exchange inflows and Turkey needs to reduce its huge stock of foreign debt that is almost half the GDP.

The production function combines the increments of domestic capital (KDN_t), foreign capital (KFN_t), labor force (LN_t), imported intermediates ($INTN_t$), electricity (EN_t), oil&gas (PN_t) and solids (SN_t) with a constant elasticity of substitution σ ($\sigma = 1/(1-\rho)$) among primary factors, intermediates and energy to produce gross output:

$$YN_t=\gamma_t\{\alpha_t[(KDN_t^{skd}KFN_t^{skf})^{sk}LN_t^{sl}]^{\rho}+\beta_t INTN_t^{\rho}+(1-\alpha_t-\beta_t)[EN_t^{s}PN_t^{sp}SN_t^{ss}]^{\rho}\}^{1/\rho}$$

The surviving part of existing stocks ($STOCK_t$) is computed by means of a survival factor λ ; increments, i.e. new stocks ($STOCKN_t$) during a p-year period are added to surviving stocks

$$STOCK_t = STOCKN_t + \lambda^p\, STOCK_{t-1}$$

where *STOCK* stands for *Y, KD, KF, L, INT, E, P* and *S*.

Gross domestic product (GDP_t) is the sum of consumption (C_t), domestic investments (ID_t), imported capital goods (IF_t) and net exports (NX_t):

$$GDP_t = C_t + ID_t + IF_t + NX_t\ .$$

Two alternative types of environmental taxes have been defined: a charge on the level of emissions and a charge on the sulphur content of fuels. They are exogenously incorporated as explained below:

a) Total pollutant emissions (NOX_t, $SO2_t$), which are computed as a by-product of energy activities, are multiplied by the tax charge per unit of pollutant emitted (t_{NOX} *and* t_{SO2}) giving the total emission tax $TAX1_t$

$$TAX1_t = NOX_t \, t_{NOX} + SO2_t \, t_{SO2} \;;$$

b) The total sulphur tax, $TAX2_t$, is computed by multiplying the amount of sulphur contained in fuels ($FUEL_{j,t} \; s_j$) by the per unit sulphur tax ($t_{sulphur}$):

$$TAX2_t = \sum_j FUEL_{j,t} \; s_j \; t_{sulphur} \, .$$

where j indicates the type of energy carrier. Only one type of tax is allowed at-a-time; accordingly, the final tax (TAX_t) is taken as one of either type depending on which is applied:

$$TAX_t = TAX1_t \qquad \text{or} \qquad TAX_t = TAX2_t \; .$$

Energy cost EC_t is the sum of $FUEL_{j,t} \; c_{j,t}$, the cost of energy activities in period t including both fuel and operating costs as well as capital charges, and $PR_{x,a,j,t} \; prc_{x,a,j,t}$, the cost of emission abatement technologies :

$$EC_t = \sum_x \sum_a \sum_j \left(FUEL_{j,t} \, c_{j,t} + PR_{x,a,j,t} \, prc_{x,a,j,t} \right)$$

where the indices x and a indicate the types of pollutant and abatement technology respectively. In this way a gross energy cost ($\overline{EC_t}$) is computed as:

$$\overline{EC_t} = EC_t + TAX_t \quad .$$

Gross production (Y_t) is then the sum of GDP_t , $\overline{EC_t}$ and imported intermediates (INT_t):

$$Y_t = GDP_t + INT_t + EC_t + TAX_t \quad .$$

Thus gross output comprises GDP, payments for noncompetitive intermediate imports, energy costs and pollution taxes. Components of gross output other than GDP are of course already contained in GDP and therefore the model involves deliberate double counting that allows representing the interdependency between energy activities and the economy.

Capital accumulation occurs via investment accumulation as follows:

$$KDN_t = 0.5\,p\,(ID_t + ID_{t-1})$$

$$KFN_t = 0.5\,p\,(IF_t + IF_{t-1})$$

where p is the period length in years.

A foreign exchange constraint limits imports (M_t) so that they do not exceed the sum of exports (X_t), foreign capital inflows (F_t), tourism revenues (TR_t) and factor incomes from abroad (W_t):

$$X_t + F_t + W_t + TR_t \geq M_t$$

The imported portion of investments (IF_t), intermediates (INT_t), fuels (EF_t) and consumption goods (CG_t) make up total imports:

$$M_t = IF_t + INT_t + EF_t + CG_t$$

Energy-economy interaction is represented via energy demand and cost relations that can be summarised as:

$$[E_t, P_t, S_t] = [A_t]\,[z_t] \quad \text{and}$$

$$[EC_t, EF_t] = [B_t]\,[z_t]$$

where $[z_t]$ is a vector representing energy activities and $[A_t]$ and $[B_t]$ stand for the technology and cost matrices respectively (details of the energy model are given in appendix A).

An overall utility function is defined as the discounted logarithm of consumption;

$$U = \Sigma_t\, (1/(1+\delta))^t \; \log\,(C_t) \quad .$$

4.2.2. Endogenising Pollution Abatement

An alternative way of treating the environmental impact of energy activities would be to reflect the adverse effects of pollution in the utility function assuming that there will be no pollution taxation. In the basic version of ENVEES presented above, pollution abatement is effected via environmental taxation. However, driven by environmental consciousness, people engage to some extent in voluntary pollution abatement activities. Consumers tend to prefer less-polluting goods and services so long as they are able to. In other words, the level of pollution generated during economic activity affects consumers' utility. This is the motivation in attempting to incorporate the effect of pollutant emissions into the utility function and "endogenise" pollution abatement. Various authors (e.g. Baumol et al., 1993; Hodgson, 1997) suggest including environmental considerations into the utility function to correct for market failures, although no such applied study can be traced at this time.

In our efforts to endogenise pollution abatement, *a preference rate*, which is related to the level of pollutant emissions, is incorporated into the utility function. This quality-of-life penalty function approach is consistent with the proposal made by Baumol et al. (1993) in their book on the theory of environmental policy to formulate a utility function in which the level of utility depends on the level of consumption and the level of environmental quality. The discounted utility function U is accordingly defined as

$$U = \Sigma_t \, (1/(1+\delta))^t \log \left((a\, C_t)^{\alpha(EI_t)} \right) \quad \text{where} \quad 0 < a\, C_t < 1 \, .$$

where a is a scale parameter, δ stands for the discount factor, and $\alpha(EI_t)$ denotes a preference rate for clean air depending on the emission index EI_t. The index makes it possible to monitor changes in total emissions over the years. It is formulated as a weighted index of pollutants emitted into the atmosphere and is scaled to take a unitary value in the base year. Specifying weights, w_{NOX}, w_{SO2} for each pollutant, the evolution of the emission index is as follows:

$$EI_{t+1} = (1-\chi_t)\, EI_t + (w_{NOX}\, NOX_{t+1} + w_{SO2}\, SO2_{t+1}) / (NOX_{Base} + SO2_{Base})$$

The weights can be obtained by a public opinion poll as suggested in Hope et al. (1990, 1992) or subjective value judgement can be used. In the above equation, χ_t is taken as a clean-up rate due to technical progress and *NOX* and *SO2* stand for nitrogen and sulphur emissions respectively. Depending on the index of emissions, the preference rate $\alpha(EI_t)$ is defined as a function of the percent deviation from a maximum index (EI_{max}) which may be computed using regulations or subjective judgement. Accordingly, the proposed form is

$$\alpha(EI_t) = -\, \alpha_0 \log((EI_{max} - EI_t) / EI_{max}) + \alpha_1$$

where α_0 and α_1 are nonnegative parameters. Here, the preference increases with a rising index since the discrepancy between the maximum and actual indices decreases. Accordingly, the preference rate is an increasing function of emissions on logarithmic scale to give values between 0 and 1. A similar indicator is used in Beaumais et al. (1995) but it expresses the level of deterioration as an absolute quantity depending on the total accumulation of wastes. This model specification endogenising pollution abatement is proposed as a transitory medium for endogenising environmental taxes; calibration details are therefore not discussed further.

According to the above formulations, utility maximisation limits the growth of the preference rate, which in turn forces a decrease of the growth in pollutant emissions. Such an inclusion of environmental concern in the utility function leads the model to change the energy mix and use abatement technologies without setting any tax or external emission limits.

It is clear that endogenising pollution abatement in this way is not established in modelling practice and might raise questions about the underlying economics. Still it simulates the pollution-abating behaviour of consumers and is not inconsistent with microeconomic theory.

4.2.3. Endogenising Environmental Taxes

Environmental taxes have been incorporated into the basic version of ENVEES as an exogenous instrument, which will induce pollution abatement. The tax is fixed by trial and error so as to achieve a certain amount of emission reduction. This procedure does not allow for a consistent framework to work out effective tax strategies – it is necessary to endogenise taxes in order to come up with 'optimal' strategies.

In order to endogenise the emission tax, a cost-based penalty function approach is used. The same logic followed in endogenising abatement is utilised. First, the emissions (in index form, EI_t) and the emission tax are taken as substitutes and modelled within a CES functional form. The inverse relationship between the emission index and the emission tax is modelled as follows:

$$EITX_t = b\ (EI_t^{\rho} + (1/(TAX1_t))^{\rho})^{1/\rho}.$$

Depending on this aggregate ($EITX_t$), a preference rate $\beta(EITX_t)$ is specified as

$$\beta(EITX_t) = -\ \alpha_2 \log((EITX_{max} - EITX_t) / EITX_{max}) + \alpha_3$$

and utility is defined as

$$U = \Sigma_t\ (1/(1+\delta))^t \log ((a\ C_t)^{\beta(EITX_t)}) \text{ where } 0 < a\ C_t < 1.$$

This formulation induces the model to decrease the emission index while increasing the emission tax. More specifically, maximisation of the utility function necessitates limiting the growth of the preference rate $\beta(EITX_t)$. Accordingly, $\beta(EITX_t)$ is reduced. This is achieved by a combination of two ways: increasing the emission tax and decreasing the emission index. This functioning explains also the logic behind the inversely related CES-formulation of tax and emissions. The timing and level of emission taxes is endogenised with this specification.

Similar to the abatement-endogenising model version developed in the previous section, the attempt of endogenising environmental taxation in these kind of models is the first study of its art. It might again raise questions about the underlying economics; however, this version also behaves fairly well and is once more consistent with microeconomic theory.

4.3. Model Calibration

The model has been calibrated using 1991 data for Turkey. This year has been chosen as the base year since it is an ordinary year in which no extraordinary political, social or economic events have taken place. Energy and economic balances for the reference year 1991 are summarised in Box1.

Economic Balances (10^9 US $)*

GDP	151.113
Consumption	130.011
Total Investments	28.553
Investments made with Foreign capital goods	6.060
Domestic Investments	22.493
Energy Investments	2.111
Tourism Revenues	2.654
Tot. Outstanding Debt	41.372
For. Capital Inflow	0.783
Workers' Remittances	2.819
Exports	13.593
Imports	21.047

Import Composition*

Intermediates	12.597
Fuels	2.580
Cons. Goods	1.575
Capital Goods	4.295

Energy Balances (MTOE)**

	Domestic	Imported
Hardcoal	1.827	4.664
Lignite	9.103	0.560
Natural Gas	0.185	3.672
Petroleum	4.674	20.862

	Electric	Nonel. use
Hardcoal	0.351	6.140
Lignite	5.587	4.076
Petroleum	1.205	24.331
Natural Gas	2.614	1.243

Electricity (Twh)**

Total	60.246
Hydro	22.683
Lignites	20.563
Hardcoal	0.998
Natural Gas	12.589
Fuel-Oil	3.332

* http://www.dpt.gov.tr
** 1991 Energy Report, WEC Turkish National Committee

Box 1. Reference year Energy and Economic Balances

4.3.1. Main Assumptions and Model Parameters

The main base case assumptions of the model are summarised in Box 2. They are essentially based on government reports and expert judgements. The assumptions are to a large extent consistent with the MEEET study; details for the calibration of production function parameters and the computation of energy prices can be found in Kumbaroğlu (1995). However, various parameter values are updated to year 2000 based on expert guesses as explained in section 4.3.2. Model sensitivity to key parameters is explored in section 5.1.

Macroeconomic assumptions

Cost and utility discount rate : 8%
Labor force growth rate : 1.5%
Productivity growth rate : 1.5%
Workers' remittances gr. rate : 4.0%
Tourism revenues growth rate : 6%
Capital/output ratio : 3.0
Value share of capital in capital-labor pair : 65%

- Share of domestic capital : 70%
- Share of foreign capital : 30%

Value share of labor in capital-labor pair : 35%
Share of electr. in energy aggreg : 45%
Share of oil&gas in energy aggr. : 31%
Share of solids in energy aggreg : 24%
Elasticity of substitution between pairs of the production function : 30%
Survival factor capital goods : 97%
Survival factor intermediates : 99%
Survival factor labor : 98.5%

Upper Bounds

Imports : 25% of GDP
Exports : 25% of GDP
Cons. Goods : 4% of GDP
For.Cap.Inflows : 3% of GDP

Fuel prices (\$/10^6 Btu)

Lignite 1 : 29.67
Lignite 2 : 5.46
Lignite 3 : 2.29
Lignite 4 : 5.46
Hardcoal : 3.34
Natural gas : 3.76
Oil : 3.06

Electricity Cost (cent/kwh)

HydroA; 1:3.51 2:4.62 3:5.73
HydroB; 1:1.75 2:2.31 3:2.86
Lignite: 1:12.13 2:3.86 3:2.78
Natural gas : 3.24
Nuclear : 4.33
Fuel-oil : 4.46
Hardcoal : 4.35

Fuel prices' growth rates

Solids: 1% Oil: 2.5%
Natural gas: 2%

Production function parameters

α=0.841 β=0.00019
γ =0.430

Box 2. Base Case Assumptions

4.3.2. Assumptions Pertaining to General Economic Aspects

Assumptions pertaining to general economic aspects, which are implicit in the model formulation, are summarised as follows:

- A unitary elasticity of substitution exists between capital and labor and also among the energy aggregates; electricity, oil & gas, and solids.

- A constant elasticity of substitution exists between the capital-labor pair, the electricity-oil&gas-solids aggregate, and imported intermediates.

Altered parameter values of the MEEET study pertaining to general economic aspects are explained as follows:

- In regard of the fact that $F_t \leq 0.04\ GDP_t$ leads to a high debt build-up, the upper limit on foreign capital inflows has been reduced to 3% of GDP.

- Assuming a 1.5% decline in labor inputs due to technological progress, the corresponding parameter λ in the equation $INPUT_t = INPUTN_t + \lambda^p\ INPUT_{t-1}$ has been increased from 0.97 to 0.985 for labor inputs in order to avoid labor-specific productivity growth (since the production function already includes total productivity growth). Similarly, λ has been increased from 0.97 to 0.99 for the input of imported intermediates as these stocks are less prone to attrition than capital stocks.

4.3.3. Assumptions Pertaining to Energy Supply Alternatives

Costs of electricity generation are computed on the basis of the data given in Table 4.1.

Table 4.1. Economic Data for Power Plants

Fuel Type	Investment Cost ($/kw)	Fuel Cost ($\$/10^6$ BTU)	O&M - Fixed Cost ($/kw -month)	O&M-Variable Cost ($/ Mwh)
Lignite 1	1200	29.67	1.97	1.38
Lignite 2	1200	5.46	1.97	1.38
Lignite 3	1200	2.29	1.97	1.38
Hardcoal	1000	3.34	3.59	1.56
Natural Gas	500	3.76	2.13	0.36
Nuclear	2000	2.08	3.43	0.59
Fuel-Oil	1200	8.49	0.19	0.04
Hydro 1	750	-	0.30	-
Hydro 2	1000	-	0.30	-
Hydro 3	1250	-	0.30	-

Basic assumptions pertaining to energy supply alternatives are summarised as follows:

- Power plants are assumed to have a useful life of 30 years with straight-line depreciation.

- An average of 7000 hours per year has been assumed for thermal operation.

- Thermal power plants are classified into five main groups according to the fuel they use, lignite, hardcoal, natural gas, nuclear and fuel-oil.

- Hydro plants are divided into six groups according to their load factors and investment costs. Two groups are defined according to whether the load factor is less than 30% or not. Each of those two groups differentiates three types of hydro plants based on investment costs.

- Lignites are divided into four groups according to their calorific costs.

- Renewable energy alternatives are not included in the model since these constitute presently a negligible share in Turkey's energy system. Official projections do not foresee a significant increase in this share over the next twenty years.

4.3.4. Assumptions Pertaining to the Environmental Submodel

The parameter set for the environmental submodel covers assumptions on the costs of different abatement technologies, the pollutant removal efficiencies of abatement processes and emission factors. Emission characteristics of different energy conversion technologies in the model are represented by means of emission factors; they describe the resulting emissions per unit of energy flow. Turkey-specific emission factors are provided in Table 4.2, they are taken from a Ph.D. study on energy and emission control strategies for Turkey (Plinke, 1992) in which the emission factors have been computed from a comprehensive analysis of chemical properties of Turkish fuels. The emission factors given in Table 4.2 are in accordance with the plantwise emission factors from the Turkish Electricity Generation and Transmission Corporation (TEGTC, 1996) which are based upon measurements.

Table 4.2. Emission Factors
(Source: Plinke, 1992)

Fuels	Electricity Ton/10^{12}kwh	Industry Ton/10^{15}Btu	Cement Ton/10^{15}Btu	Households Ton/10^{15}Btu	Transport Ton/10^{15}Btu
Petroleum					
NO_x	2,360,000	158,259	569,732	126,607	701,615
SO_2	3,407,064	714,627	714,627	714,627	148,763
Hardcoal					
NO_x	3,200,000	168,810	232,113	54,863	-
SO_2	2,360,261	691,064	691,064	691,064	
Nat. Gas					
NO_x	540,000	105,506	105,506	55,918	-
SO_2	637,811	186,746	186,746	186,746	
Lignite 1					
NO_x	3,010,000	158,259	211,012	122,914	-
SO_2	21,999,219	2,321,132	1,508,735	1,295,614	
Lignite 2					
NO_x	3,010,000	158,259	211,012	122,914	-
SO_2	60,768,327	2,321,132	2,321,132	1,511,901	

The Wet Limestone and Wellmann Lord processes are considered as feasible emission reduction technologies for sulphur and SO_2 abatement, Primary Measures and Selective Catalytic Reduction are considered as feasible emission reduction technologies for NO_x abatement. The cost data of pollution abatement technologies is based on the assumptions given in Table 4.3; the data in the table are taken from the Plinke (1992) study which specifically considers Turkish fuel properties and technology-specific factors (e.g. the high sulphur content of some Turkish lignites necessitating higher consumption of absorbents and energy as well as larger dimensions of limestone preparation plants, absorber circuits and absorber bottoms).

Table 4.3. Economic Data for Pollution Abatement Technologies

Technology	Spec. Investment ($/kw)	Fixed O&M Cost ($/kw - year)	Var. O&M Cost (cent/kwh)
• SO2 Reduction			
Wet Limestone Pr.			
Coal	127.88	5.73	0.02
Lignite 1	288.15	12.85	0.13
Lignite 2	210.53	9.35	0.12
Oil	139.05	6.19	0.03
Wellman Lord Pr.			
Lignite 1	541.68	24.54	- 0.47
Lignite 2	395.37	17.88	- 0.40
• NOX Reduction			
Primary Measures			
Coal	10.89	-	-
Lignite 1	13.35	-	-
Lignite 2	11.95	-	-
Oil	9.94	-	-
Gasturbine	2.01	-	-
Selective Cat. Red.			
Coal	87.12	9.93	0.04
Oil	58.64	4.56	0.03
Gasturbine	49.70	2.22	0.01

Other basic assumptions pertaining to the environmental submodel are summarised as follows:

- Abatement technologies are assumed to have a useful life of 30 years with straight-line depreciation.

- Lignites are divided into two groups according to their calorific values and sulphur contents in order to account for the difference in SO_2 emissions they cause.

- Four different energy utilisation sectors (industry excluding cement production, cement production, households and transport) with exogenously fixed shares are distinguished in order to account for sectoral emission differences.

4.3.5. Assumptions Pertaining to the Utility Function and Tax Issues

This section describes the microeconomic theory behind the modified utility function to ensure that the integration of the proposed environmental preference rate does not violate the underlying axioms of choice. The calibration details of the environmental preference rate are also presented in this section.

4.3.5.1. Underlying Axioms of Choice for the Proposed Utility Function

In order to check that the proposed functional form possesses the properties of a utility function, the underlying axioms of choice (Jehle, 1991) which characterise the structure and properties of preferences, have been checked. In this context, the first and second order derivatives of the proposed utility function $U=(1/(1+\delta))^t \log (aC_t^{\alpha(EITX_t)})$ are computed as follows:

$$\frac{\partial U}{\partial C_t} = (1/(1+\delta))^t \frac{\alpha(EI_t)}{C_t \, \lambda n 10} \quad , \quad \frac{\partial U}{\partial \alpha(EI_t)} = (1/(1+\delta))^t \frac{\lambda n(a\,C_t)}{\lambda n 10} \quad ,$$

$$\frac{\partial^2 U}{\partial C_t^2} = -(1/(1+\delta))^t \frac{\alpha(EI_t)}{C_t^2 \ln 10} \quad , \quad \frac{\partial^2 U}{\partial C_t \ \partial \alpha(EI_t)} = (1/(1+\delta))^t \frac{1}{C_t \ln 10} \quad ,$$

$$\frac{\partial^2 U}{\partial \alpha(EI_t) \ \partial C_t} = (1/(1+\delta))^t \frac{1}{C_t \ln 10} \quad , \quad \frac{\partial^2 U}{\partial \alpha(EI_t)^2} = 0 \quad .$$

Since the Hessian turns out to be symmetric, it is concluded that the utility function possesses the properties of existence and continuity thus satisfying the four basic axioms of choice characterising completeness, reflexivity, transitivity and continuity of preferences. These axioms ensure that the consumer can make binary choices, that the choices are consistent, and that the preference relation possesses a certain amount of topological regularity.

Although it is not essential for representability and simplifies the purely mathematical aspects of the problem, the classical requirement on tastes that preferences be monotonic is also explored. A closer look on the first-order partial derivatives shows that the gradient vector is not always positive. This suggests that the axiom of monotonicity is invalid, however there is no problem with this since the logic behind the proposed utility function supports this finding. The monotonicity axiom simply says that if some consumption bundle A involves more of at least one commodity and no less of any other commodity than another consumption bundle B, then A will be strictly preferred to B. In the proposed form on the other hand this is not true since more is not always preferred to less, i.e. more emissions are not preferred to less emissions but vice versa. Therefore it turns out that $\partial U/\partial C_t > 0$ whereas $\partial U/\partial \alpha(EI_t) < 0$ in this case.

Although the monotonicity axiom is not satisfied, it is found that preferences satisfy the weaker axiom of local non-satiation. This is concluded by identifying that the first-order partial derivatives are strictly positive or negative but do not vanish. As a result, the possibility of having zones of indifference is ruled out so that there always exists at least one other choice, which the consumer prefers. In other words, the local non-satiation axiom is satisfied.

Finally, from an investigation of the above derivatives it can be seen that the proposed utility function satisfies the property

$$(\alpha(EI_t),\ C_t)^T\ [\text{Hessian of } U(\alpha(EI_t),\ C_t)]\ \ (\alpha(EI_t),\ C_t) \leq 0 \quad \text{for} \quad \forall(\alpha(EI_t),\ C_t)$$

$$\text{Subject to}\ \ (\alpha(EI_t),\ C_t)^T\ [\text{Gradient of } U(\alpha(EI_t),\ C_t)] = 0\ \ .$$

This implies that the proposed function is strictly quasiconcave, thus satisfying the strict convexity axiom on tastes. That is, the consumer strictly prefers any relatively balanced bundle to both of the extremes between which he/she is indifferent.

4.3.5.2. Calibration of the Environmental Preference Rate

The environmental pereference rate is computed through the index of emissions as has been explained in section 4.3. It is assumed that the index takes a unitary value in the base year 1991 in which the total amount of sulphur dioxide and nitrogen oxide emissions have been in the order of 2.19 million tons. Considering European regulations which, including a 10% tolerance, imply a maximum of 4.8 million tons of total emissions per year (Plinke, 1992) and computing the maximum emission index accordingly results in an allowance for the emission index to become at most 2.19 times higher than its initial unitary value. Substituting the conditions of maximum and base values in the preference rate specifications and assuming that the emission index takes a unitary value in the base year and that it can at most triple at maximum emission level yields the two equations

$$\alpha(EI_{max}) = -\alpha_0 \log((2.19 - 2.18\bar{9}) / 2.19) + \alpha_1 = 3 \qquad \text{and}$$

$$\alpha(EI_{base}) = -\alpha_0 \log((2.19 - 1) / 2.19) + \alpha_1 = 1 \quad .$$

Assuming a minor deviation in the order of 10^{-8} from the maximum emission index in the first equation, the solution of both equations gives $\alpha_0 \approx 0.25$ and $\alpha_1 \approx 0.94$

Next, some economically negligible minimum tax value of 10 cents per ton pollutant has been assumed to compute the elasticity of substitution of the emission index-tax aggregate. Scaling the aggregate such that it becomes at most 100, the elasticity of substitution is found to be 1.3 satisfying the following equation:

$$EITX_{max} = (2.19^{0.23} + (1/0.1)^{0.23})^{1/0.23} \approx 100 \quad .$$

Similarly, the base emission index-tax aggregate can be found to be in the order of 75, using a unitary emission index in the base year. However, these are cases where no economically significant tax is applied. The formula results in a much lower emission index-tax aggregate when an emission tax is applied. The minimum emission index-tax aggregate is computed by using the results of an exogenous high-tax scenario, obtained with the basic version of ENVEES presented in section 4.2.1 , as a benchmark. The results of a 500 dollars per ton SO_2 and NO_x scenario have been used, yielding total emissions of 4 million tons in 2025. This gives an emission index of 1.83 and a minimal emission index-tax aggregate is accordingly computed as follows:

$$EITX_{min} = (1.83^{0.23} + (1/500)^{0.23})^{1/0.23} \approx 4 \quad .$$

The minimum preference rate is assumed to take unitary value and it is assumed that it can at most triple at a maximum emission index-tax aggregate. Accordingly, the relevant parameter values are computed from the equations

$$\beta(EITX_{max}) = - \alpha_2 \log((100 - 99) / 100) + \alpha_3 = 3 \quad \text{and}$$

$$\beta(EITX_{min}) = - \alpha_2 \log((100 - 4) / 100) + \alpha_3 = 1$$

as $\alpha_2 \approx 1$ and $\alpha_3 \approx 0.99$.

CHAPTER V

NUMERICAL RESULTS OF ENVEES

The basic model was presented in Chapter IV. Our main objective is to investigate the interdependency between the economic and the environmental aspects and outcomes of energy policies. For this reason we investigate a number of different model specifications. These include (i) enforced observance of exogenously defined abatement measures in accordance with for example, the European Union emission standards; (ii) emission taxation; (iii) pollutant taxation; (iv) endogenised abatement based on a quality-of-life penalty function and (v) endogenised taxation based on a cost-based penalty function. Each of these specifications are implemented in the face of uncertainties relating to future energy prices and economic growth rates. Model calibration is carried out on the basis of replicating the performance of the Turkish economy from 1991 – the base year – to 2000 and on a reference-case scenario comprising official projections of basic economic and energy-related indices as already explained in section 4.3. The model is written using the GAMS (Brooke et al., 1988) model-generation software and solved by the nonlinear programming solver MINOS (Murtagh et al., 1980).

This chapter reports on results obtained from the various specifications of the model under variations of the reference scenario. The reference case, or the BAU (business-as-usual) scenario does not place any restrictions or penalties on energy activities to reduce environmental effects. The BAU results are presented first. Model forecasts for the period from 1991 to 2000 are compared to actual data for a partial validation of the model. Validity is further questioned by computing and evaluating the implied income and price elasticities of energy demand indirectly through simulated experiments. Finally labour force and productivity growth are varied to establish the sensitivity of the solutions to these exogenously specified trajectories that drive the model.

After presenting preliminary results, the rest of the chapter discusses Turkish energy policies based on solutions obtained with different model specifications. First, a number of non-environmental scenarios (scenarios that do not target emission reduction) are defined in order to investigate consequences of currently relevant energy policy issues in Turkey. These scenarios address the question of whether and when to introduce nuclear power and the question of what economic impacts different energy price trajectories cause. These issues are investigated with the base model. The importance of nuclear energy for the Turkish energy system is investigated under different cost assumptions as well as under various anti-nuclear scenarios. The impact of imported energy prices on energy and economic policies are explored under a set of varying oil and gas price assumptions. Secondly, a number of environmental scenarios are defined that aim to reduce pollutant emissions to European standards. These scenarios include different economic measures such as direct control, pollutant taxation and emission taxation. Direct control is simulated in the base model by setting upper limits on annual emissions. Exogenously defined pollutant and emission taxes are simulated using the tax-integrated model specification described in section 4.2.1. The chapter also presents results from "endogenising" specifications; these include endogenised pollution abatement results obtained with the specification explained in section 4.2.2 and endogenised emission taxation results obtained with the specification explained in section 4.2.3. The final section elaborates on the interaction of environmental policies with energy decisions.

5.1. Model Validation and Sensitivity to Key Parameters

Assumptions and parameter that define the reference path of the BAU scenario as well as data for the reference year were given in section 4.3. This section first compares BAU results for initial periods with actual data to explore partial model validity. Model validity is further investigated by computing the implicit price and income elasticities by simulated experiments. The sensitivity of model results to variations in explicit parameters, such as labor force and productivity growth rates, is also explored.

5.1.1. Model Performance for Initial Periods

The model has been calibrated taking 1991 as the base year. The first period solutions are for the year 1995 and results are obtained for five-year periods thereafter. In order to establish the validity of the model, BAU-projections obtained from the base model up to year 2000 are compared to actual data and also to latest official forecasts as of October 2000. The comparison of economic indicators is presented in Table 5.1 and that of energy indicators, in Table 5.2. It is observed from these tables that model solutions and actual realisations and forecasts are very close. The discrepancy between projected and actual values of energy and economic indicators is within a tolerance of +/- 2% except for year 2000 hydroelectric energy. Based on the first 8 months' production levels total hydroelectric energy production should be about 30-35 Twh at the end of the year, which is well below the model forecast of 48.83 Twh. 2000 has been an extraordinarily dry year however and does not reflect the usual situation. It is worth noting that in 1998, hydroelectric energy production has been 42.23 Twh. Moreover, the model's forecast of total electricity generation in 2000 differs only 0.5% from the latest official forecasts. In regard of these and the fact that the model addresses long-term trends rather than short-term fluctuations, the model forecasts appear to be acceptable.

Table 5.1. Comparison of Economic Forecasts to Actual Realisation (10^9 \$)

	1995		2000	
	Forecast	Realisation	Forecast	Realisation
GDP	168.483	169.841	200.900	201.010[2]
Investment	41.982	41.182	59.510	57.155[2]
Exports	21.219	21.637	30.993	30.730[2]
Total Imports	35.778	35.709	48.623	47.409[2]
Import Composition:				
Cons. Goods	2.390	2.416	4.612	3.223[1]
Cap. Goods	8.034	8.119	10.720	4.936[1]
Fuels	3.150	3.015	7.021	2.901[1]
Intermediates	22.204	22.159	26.270	13.860[1]

[1]: 6 Months' realisation (January-June)
[2]: Official forecast

Table 5.2. Comparison of Energy Forecasts to Actual Realisation

	1995		2000	
	Forecast	Realisation	Forecast	Realisation
Electricity (Twh)	86.126	86.247	127.508	126.800^2
Oil & Gas (Mtoe)	35.010	35.542	50.923	50.820^2
Solids (Mtoe)	22.466	21.987	32.477	32.902^2
Electricity Composition (Twh):				
Hydro	35.529	35.541	48.829	23.250^1
Natural Gas	17.560	16.579	33.982	28.701^1
Lignite	25.355	25.815	33.384	22.060^1
Hardcoal	2.327	2.232	3.074	2.374^1
Fuel-Oil	5.356	5.772	8.239	6.479^1
Nonelectric Energy Composition (Mtoe):				
Natural gas	3.181	2.940	7.577	7.208^2
Hardcoal	4.453	4.221	10.708	10.107^2
Lignite	3.872	3.678	4.791	4.271^2
Petroleum prod.	25.712	24.943	32.746	30.185^2

[1]: 8 Months' realisation (January-August)
[2]: Official forecast

5.1.2. Partial Model Validation by Exploration of Income and Price Elasticities Implied in the BAU Scenario

The income and price elasticities of energy demand are key parameters implicit in the model. The income elasticity of energy is a measure of the economic effects of changed energy availability. To determine the income elasticity, the results of the BAU scenario can be compared with those of a high growth scenario. The difference Δ in total primary energy consumption (*E*) and in GDP can be computed to determine the implied income elasticity (η):

$$\eta = \Delta \ln(E) / \Delta \ln(\mathrm{GDP}) \quad .$$

The high growth scenario assumes faster labour force growth and faster technological change. The respective growth rates are henceforth simultaneously increased from 1.5% to 1.7% from 2005 on. The total energy demand, GDP and the implied income elasticity are given in Table 5.3. It can be seen from Figure 5.1 that the income elasticity varies between 0.97 and 1.58 without any special trend. Only in 2005 there is an initial high of 1.58 and thereafter the elasticity remains within the range 1-1.3. In developed countries, the income elasticity of energy is usually in the order of 0.6-1. The comparatively high level in Turkey that seems to fluctuate around 1.2 as shown in Figure 5.1, is typical for a developing country in which high levels of economic activity generate even higher energy demand.

Table 5.3. Computed Income Elasticities

	Base Case		High Growth		Income Elasticity
	Energy (Mtoe)	GDP (10^9 $)	Energy (Mtoe)	GDP (10^9 $)	
2005	97.894	249.936	101.371	255.511	1.582
2010	119.125	309.690	125.189	323.419	1.145
2015	146.089	380.365	154.930	404.154	0.969
2020	187.562	469.846	202.834	500.506	1.238
2025	239.882	577.731	256.773	608.203	1.324
2030	298.461	710.509	310.541	734.726	1.184
2035	366.947	876.125	376.865	895.445	1.223
2040	442.351	1087.522	456.601	1113.600	1.338
2045	541.660	1331.583	583.019	1414.683	1.215
2050	653.409	1604.415	736.311	1785.916	1.114

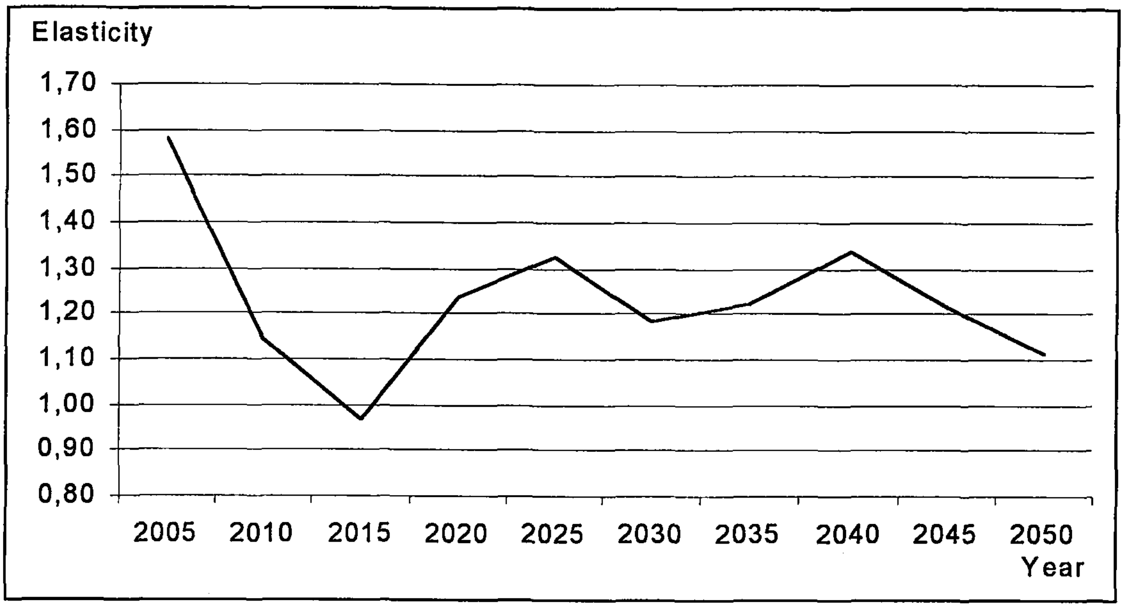

Figure 5.1. Income Elasticity Development

Similar to the above computation, the price elasticities of energy demand are computed by using the formula

$$\eta = \Delta \ln(q) / \Delta \ln(p) \quad .$$

where q represents the energy demand and p denotes its price. The differences are computed between the reference run and the high-price scenario. The high price scenarios assume a fast price increase for energy at 10% per year. The implicit price elasticities are computed for electricity, petroleum, natural gas and nuclear power. There are differing opinions on the computation of the aggregate elasticity of electricity demand due to differences in the aggregation of various energy sources. The most common form of aggregation, a Btu-weighted index, is used below in computing the aggregate electricity price. Results are summarised in Table 5.4 and illustrated in Figure 5.2.

Table 5.4. Price Elasticities of Energy Demand

	Electricity	Oil	Natural gas
2005	-0.02124	-0.06461	-1,56257
2010	-0.05441	-0.17343	-1,35146
2015	-0.06708	-0.27410	-1,11924
2020	-0.07643	-0.35161	-0,79627
2025	-0.08398	-0.39475	-0,51779
2030	-0.08804	-0.38519	-0,25490
2035	-0.10279	-0.39036	-0,37260
2040	-0.14201	-0.38917	-0,57685
2045	-0.18395	-0.39147	-1,03650
2050	-0.19458	-0.38884	-1,34325

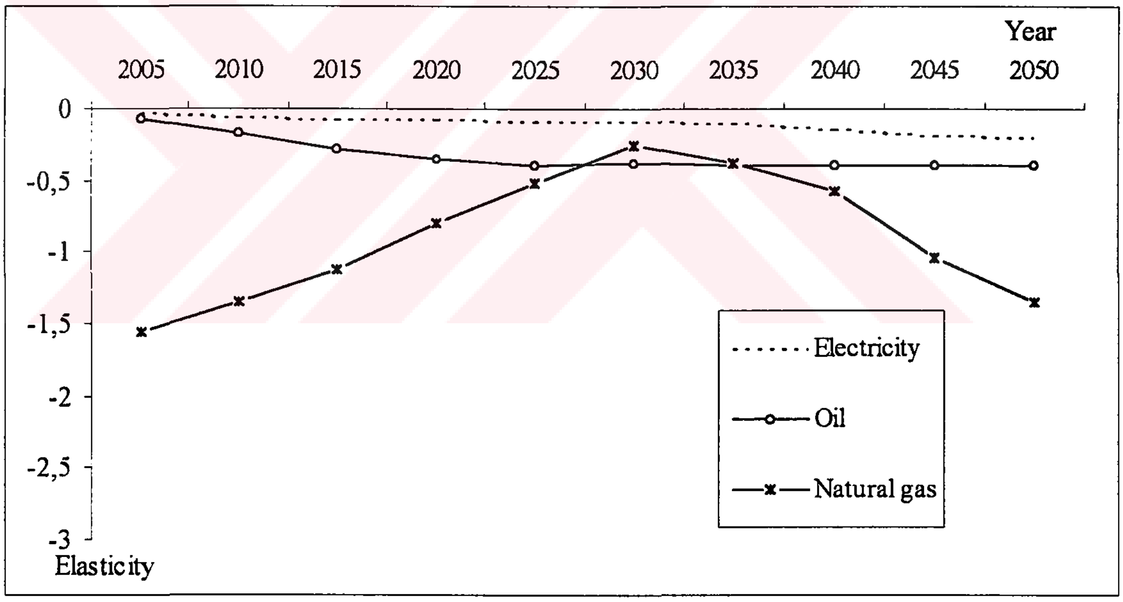

Figure 5.2. Energy Price Elasticities

Electricity demand seems to be the least elastic and the demand for gas the most elastic as would be expected in view of the difficulty of substituting other forms of energy for electricity and the relative ease in the case of natural gas. It is observed that the price elasticity of natural gas does not follow a smooth path but first declines from 1.56 to 0.25 until 2030 and recovers thereafter. One possible explanation for this pattern might be the substitution capability of natural gas with other fuels and primary factors. It seems that the substitution possibilities are limited until 2030 but start to increase thereafter. This result may be interpreted as an indicator of the need for further research. The elasticity estimates for electricity follow an increasing trend from 0.021 to 0.194 indicating that price changes more heavily affect electricity demand in the long run as would be expected of any economic good. Similarly, the price elasticity of oil increases from 0.06 to 0.39 and thereafter follows a smooth path. In conclusion it can be said that the computed price elasticities seem reasonable, increasing the credibility of the model.

5.1.3. Model Sensitivity to Productivity and Growth Rate Assumptions

The exogenously specified labour force and productivity growth rates are key parameters that drive economic growth in the model. In the reference run, these are taken as 1.5% per year. This generates moderate growth for the economy in the planning period considered. In order to explore model sensitivity to variations in the labor force growth rate, additional solutions are obtained with labor force growth from 2005 onwards, taken as 1.3% and 1.7% respectively, with everything else remaining constant. The results are summarised in Table 5.5. It is observed from the table that main indicators of energy, economy and environment are positively correlated with the labor force growth rate. That is, a lower growth of labor force slows down economic growth leading to a lower GDP, reduced investments, decreased exports and imports, less energy consumption and less emissions. A higher growth of labor force accelerates economic growth inducing opposite effects.

Table 5.5. Model Sensitivity to Variations in the Labor Force Growth Rate

	2005	2010	2015	2020	2025	2030	2035
Economic Indicators							
GDP (10^9 \$): BAU	249.94	309.69	380.36	469.85	577.73	710.51	876.12
Labor f. growth 1.3%	247.84	304.67	372.07	458.01	562.34	692.77	854.10
Labor f. growth 1.7%	252.04	314.69	388.31	480.91	591.55	726.67	893.89
Investm. (10^9 \$): BAU	81.36	94.19	116.05	138.95	164.61	193.84	242.36
Labor f. growth 1.3%	79.97	92.72	114.66	138.14	161.50	189.79	230.91
Labor f. growth 1.7%	82.94	95.41	117.04	138.95	166.11	199.85	241.08
Exports (10^9 \$): BAU	40.92	51.08	62.97	78.24	96.59	119.27	147.79
Labor f. growth 1.3%	40.44	49.92	61.06	75.52	93.05	115.19	142.73
Labor f. growth 1.7%	41.41	52.23	64.80	80.78	99.77	122.98	151.88
Imports (10^9 \$): BAU	62.48	77.42	95.09	117.46	144.43	177.63	219.03
Labor f. growth 1.3%	61.96	76.17	93.02	114.50	140.58	173.19	213.53
Labor f. growth 1.7%	63.01	78.67	97.08	120.23	147.89	181.67	223.47
Energy Indicators							
Electric. (Twh): BAU	189.61	280.19	377.22	510.66	673.98	887.70	1172.63
Labor f. growth 1.3%	187.11	272.94	364.62	491.16	646.84	853.89	1127.84
Labor f. growth 1.7%	192.12	287.41	389.48	529.31	699.10	919.46	1210.61
Total Primary Energy (Mtoe): BAU	97.89	119.13	146.09	187.56	239.88	298.46	366.95
Labor f. growth 1.3%	97.70	115.14	143.25	186.04	234.04	289.10	353.47
Labor f. growth 1.7%	98.08	120.21	149.52	189.82	245.76	307.94	378.81
Environm. Indicators							
SO_2 Em.(10^6Tons): BAU	4.85	6.21	7.90	10.18	13.08	16.20	18.65
Labor f. growth 1.3%	4.85	5.90	7.51	10.00	13.04	16.07	18.01
Labor f. growth 1.7%	4.85	6.36	8.26	10.36	13.09	16.30	19.12
NO_x Em.(10^6Tons): BAU	1.01	1.13	1.27	1.50	1.79	2.09	2.44
Labor f. growth 1.3%	1.01	1.10	1.26	1.51	1.77	2.06	2.37
Labor f. growth 1.7%	1.01	1.14	1.30	1.52	1.82	2.15	2.51

Similar to the foregoing analysis, the productivity growth rate is changed to 1.3% and 1.7% and additional solutions are obtained (all else remaining constant) to explore model sensitivity to variations in the productivity growth rate. The results are summarised in Table 5.6.

Table 5.6. Model Sensitivity to Variations in the Productivity Growth Rate

	2005	2010	2015	2020	2025	2030	2035
Economic Indicators							
GDP ($10^9 \$$): BAU	249.94	309.69	380.36	469.85	577.73	710.51	876.12
Product. growth 1.3%	248.02	303.69	367.39	446.64	540.18	654.50	792.10
Product. growth 1.7%	249.56	309.68	382.32	476.11	590.89	733.00	904.00
Investm. ($10^9 \$$): BAU	81.36	94.19	116.05	138.95	164.61	193.84	242.36
Product. growth 1.3%	80.18	91.70	111.88	133.43	157.64	188.11	219.45
Product. growth 1.7%	80.57	93.36	115.28	138.43	162.71	189.80	216.14
Exports ($10^9 \$$): BAU	40.92	51.08	62.97	78.24	96.59	119.27	147.79
Product. growth 1.3%	40.48	49.70	59.98	72.90	87.95	106.38	128.47
Product. growth 1.7%	40.84	51.08	63.42	79.68	99.62	124.44	154.20
Imports ($10^9 \$$): BAU	62.48	77.42	95.09	117.46	144.43	177.63	219.03
Product. growth 1.3%	62.00	75.92	91.85	111.66	135.04	163.63	198.02
Product. growth 1.7%	62.39	77.42	95.58	119.03	147.72	183.25	226.00
Energy Indicators							
Electric. (Twh): BAU	189.61	280.19	377.22	510.66	673.98	887.70	1172.63
Product. growth 1.3%	187.34	271.67	358.54	475.16	614.27	794.24	1025.40
Product. growth 1.7%	189.11	279.88	379.29	518.93	693.06	922.75	1218.04
Oil&Gas (Mtoe): BAU	50.85	53.78	63.52	75.84	91.39	116.80	155.17
Product. growth 1.3%	50.75	50.73	54.37	62.72	78.16	97.64	127.63
Product. growth 1.7%	50.83	58.07	67.82	80.22	95.88	121.29	159.66
Solids (Mtoe): BAU	47.04	65.35	82.57	111.72	148.49	181.66	211.78
Product. growth 1.3%	46.96	68.78	95.56	123.94	146.88	176.32	200.27
Product. growth 1.7%	47.00	54.06	70.85	103.28	146.33	188.67	222.90
Environm. Indicators							
SO_2 Em.(10^6Tons): BAU	4.85	6.21	7.90	10.18	13.08	16.20	18.65
Product. growth 1.3%	4.85	6.34	8.37	10.61	12.97	15.93	17.57
Product. growth 1.7%	4.85	5.79	7.35	9.76	12.90	16.38	19.45
NO_x Em.(10^6Tons): BAU	1.01	1.13	1.27	1.50	1.79	2.09	2.44
Product. growth 1.3%	1.01	1.14	1.31	1.53	1.73	2.01	2.29
Product. growth 1.7%	1.01	1.08	1.23	1.48	1.80	2.16	2.53

It is observed from the above table that the model chooses to reduce economic activity in response to less efficient production implied by lower productivity growth. Hence economic indicators are all reduced with respect to the BAU results. Higher productivity growth on the other hand leads to faster economic growth as would be expected in a more efficient economy. Only investments decline as higher productivity would seem to imply that more output is obtained with less investment. A look at energy indicators shows that in the long run they are positively correlated with productivity growth. However, especially solids are in the short term in negative correlation leading to more solid fuel consumption when productivity growth is low. This is because cheap domestic lignites are preferred in the short term to satisfy the energy needs of the less efficient economy. Pollutant emissions are accordingly in the short run higher at lower productivity growth rates but they are reduced in the long term as solid fuel use declines.

These findings are reasonable and seem to add to the credibility of the model. In other words, the discussions of this section go some way to establish the validity of the model about which not much more can perhaps be done. A longer replication period for example will not necessarily provide greater validity since it is not clear that projections into several decades in the future should necessarily be based on the experience of past decades with quite different conditions. There is however further need to validate the backdrop to a structured inquiry into environmental issues. A chief concern would be to appraise environmental policies under different future scenarios possible, and also as they interact with energy decisions. Policies pertaining to nuclear energy are especially important in this respect. Such issues are elaborated in the following sections. First, a number of non-environmental scenarios with differing energy price and availability assumptions are defined. Although these scenarios do not target pollution reduction, their impact on emission levels is also analysed. The second scenario set includes environmental scenarios that target pollutant reduction using various measures such as emission tax, energy tax or direct control. Based on the results of non-environmental and environmental scenarios, combinations are defined that make up new scenarios which explore the interaction of environmental policies with energy decisions.

5.2. Non-environmental Scenarios

Scenario results that do not target emission reductions are discussed in this section. These scenarios address currently relevant energy policy issues and are comprised of anti-nuclear policies as well as various energy price assumptions. Two anti-nuclear scenarios are defined; one restricting new plant installations and the other banning nuclear energy altogether. Scenarios with increased nuclear power costs are also defined that are based on unofficial cost estimates which are usually higher than official estimates. Various scenarios with differing energy import price assumptions elaborate the importance of energy import prices on the Turkish economy by changing oil and gas prices and exploring model sensitivity to varying prices.

5.2.1. Anti-nuclear Scenarios

The introduction of nuclear power is a current issue in Turkey as mentioned before. In the reference run, nuclear energy is restricted to 1400 MW (which is the size of the plant planned for Akkuyu) until 2015 and is then allowed to expand by up to 50% for subsequent periods. Two additional scenarios are defined in order to explore the effect of various nuclear policies on the Turkish energy system and economy. The 'Restricted Nuclear' scenario allows no increase in additional nuclear power after 2015 and the 'Nuclear Ban' scenario totally bans nuclear power from the start. Results of both anti-nuclear scenarios are summarised in Table 5.7.

Table 5.7. Results of Various Nuclear Energy Policies

	2005	2010	2015	2020	2025	2030	2035
Economic Indicators							
GDP $(10^9\,\$)$: BAU	249.94	309.69	380.36	469.85	577.73	710.51	876.12
Restricted Nuclear	249.61	308.17	376.15	460.87	561.45	682.69	830.86
Nuclear Ban	249.26	306.81	373.61	456.63	554.61	671.80	814.90
Investm. $(10^9\,\$)$: BAU	81.36	94.19	116.05	138.95	164.61	193.84	242.36
Restricted Nuclear	80.35	91.79	110.91	130.44	151.68	173.85	214.95
Nuclear Ban	79.24	89.88	109.10	127.20	146.86	167.16	208.21
Exports $(10^9\,\$)$: BAU	40.92	51.08	62.97	78.24	96.59	119.27	147.79
Restricted Nuclear	40.85	50.73	62.00	76.17	92.85	112.87	137.38
Nuclear Ban	40.77	50.42	61.41	75.20	91.27	110.36	133.71
Imports $(10^9\,\$)$: BAU	62.48	77.42	95.09	117.46	144.43	177.63	219.03
Restricted Nuclear	62.40	77.04	94.04	115.22	140.36	170.67	207.72
Nuclear Ban	62.31	76.70	93.40	114.16	138.65	167.95	203.72
Energy Indicators							
Electric. (Twh): BAU	189.61	280.19	377.22	510.66	673.98	887.70	1172.63
Restricted Nuclear	189.15	277.71	370.69	496.14	646.88	839.21	1089.03
Nuclear Ban	188.73	275.59	366.60	489.21	635.13	819.54	1058.58
Nuclear (Twh): BAU	0	7.00	14.00	25.40	43.90	67.50	106.00
Restricted Nuclear	0	7.00	14.00	21.00	28.00	35.00	42.00
Nuclear Ban	0	0	0	0	0	0	0
Oil&Gas (Mtoe): BAU	50.85	53.78	63.52	75.84	91.39	116.80	155.17
Restricted Nuclear	50.73	57.58	66.99	79.03	94.46	119.88	158.20
Nuclear Ban	50.67	57.59	67.00	79.04	94.48	119.89	158.17
Solids (Mtoe): BAU	47.04	65.35	82.57	111.72	148.49	181.66	211.78
Restricted Nuclear	47.02	53.33	66.45	92.96	128.60	158.22	188.15
Nuclear Ban	47.02	54.01	66.03	99.76	136.39	165.17	192.96
Environm. Indicators							
SO_2 Em.(10^6Tons): BAU	4.85	6.21	7.90	10.18	13.08	16.20	18.65
Restricted Nuclear	4.85	5.75	7.14	9.34	12.20	15.20	17.10
Nuclear Ban	4.84	5.75	7.00	9.59	12.48	15.45	17.27
NO_x Em.(10^6Tons): BAU	1.01	1.13	1.27	1.50	1.79	2.09	2.44
Restricted Nuclear	1.01	1.07	1.19	1.40	1.68	1.97	2.30
Nuclear Ban	1.01	1.07	1.19	1.44	1.72	2.00	2.32

It is observed from Table 5.7 that a limit on nuclear energy causes significant economic losses; the GDP loss reaches 5% of GDP in 2035 in the case of restricted nuclear and 7% in the case of nuclear ban. It is also observed from the table that pollutant emissions under anti-nuclear scenarios are slightly lower than BAU-emissions. This is because of the reduction in energy activities as a result of lower economic growth due to anti-nuclear policies. The impact of anti-nuclear policies on pollutant emissions and their interaction with EU emission standards is further discussed in section 5.4. It is further observed from Table 5.7 that the model prefers to substitute the nuclear energy loss until 2035 by oil&gas instead of solid fuels. This is because most of the domestic lignites are low-quality so that calorie cost are relatively high in comparison to those of oil&gas. However in the long run lignites become relatively cheaper since their prices are assumed to rise by 1% per year whereas oil&gas prices rise by 2-2.5%. The effect of the long-run change in relative prices on energy consumption can be observed in Figure 5.3; after 2035 the model starts to substitute solid fuels for oil&gas. The interaction of anti-nuclear scenarios with energy price assumptions is discussed in section 5.4.

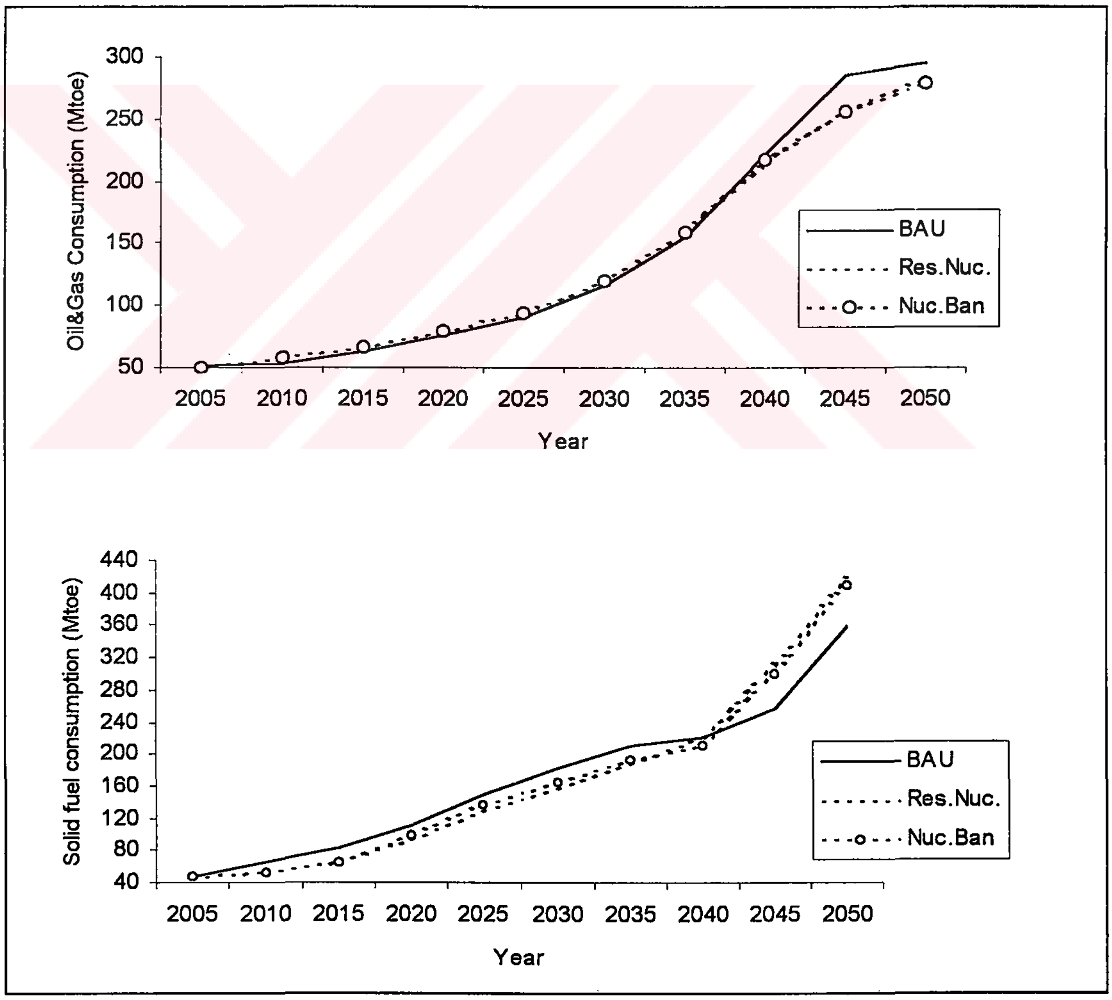

Figure 5.3. Energy Consumption with Anti-nuclear Scenarios

5.2.2. Expensive Nuclear Power Scenarios

The official cost estimate of 4.33 cents/kwh for nuclear power generation is used in the reference run. It is observed that the upper bound on nuclear power installation becomes active in the solutions at this price level. However, unofficial estimates of nuclear generation costs are usually higher, going up to 7-8 cents/kwh. Therefore, two other scenarios with higher prices are defined: one assumes the cost to be 6 cents/kwh and the other 8 cents/kwh. The results are presented in Table 5.8.

Table 5.8. Model Sensitivity to Variations in Nuclear Power Costs

	2005	2010	2015	2020	2025	2030	2035
Economic Indicators							
GDP (10^9 \$): BAU	249.94	309.69	380.36	469.85	577.73	710.51	876.12
Price 6 cents/kwh	249.93	309.70	380.17	469.19	576.31	708.08	872.17
Price 8 cents/kwh	249.92	309.65	380.14	468.76	575.22	705.98	868.16
Investm. (10^9 \$): BAU	81.36	94.19	116.05	138.95	164.61	193.84	242.36
Price 6 cents/kwh	81.35	94.22	115.87	138.53	163.99	193.04	241.23
Price 8 cents/kwh	81.32	94.15	115.80	138.24	163.64	192.15	239.71
Exports (10^9 \$): BAU	40.92	51.08	62.97	78.24	96.59	119.27	147.79
Price 6 cents/kwh	40.92	51.08	62.92	87.09	96.26	118.71	146.88
Price 8 cents/kwh	40.92	51.07	62.92	77.99	96.01	118.23	145.96
Imports (10^9 \$): BAU	62.48	77.42	95.09	117.46	144.43	177.63	219.03
Price 6 cents/kwh	62.48	77.42	95.04	117.30	144.08	177.02	218.04
Price 8 cents/kwh	62.48	77.41	95.03	117.19	143.80	176.49	217.04
Energy Indicators							
Electric. (Twh): BAU	189.61	280.19	377.22	510.66	673.98	887.70	1172.63
Price 6 cents/kwh	189.59	280.13	377.01	509.94	672.43	884.91	1168.00
Price 8 cents/kwh	189.56	280.00	376.71	509.27	671.14	882.53	1163.39
Nuclear (Twh): BAU	0	7.00	14.00	25.40	43.90	67.50	106.00
Price 6 cents/kwh	0	0	7.00	18.40	36.90	60.50	99.00
Price 8 cents/kwh	0	0	0	11.40	29.90	53.50	92.00
Oil&Gas (Mtoe): BAU	50.85	53.78	63.52	75.84	91.39	116.80	155.17
Price 6 cents/kwh	50.84	53.81	63.52	75.80	91.30	116.71	155.08
Price 8 cents/kwh	50.83	53.87	63.55	75.79	91.25	116.67	155.03
Solids (Mtoe): BAU	47.04	65.35	82.57	111.72	148.49	181.66	211.78
Price 6 cents/kwh	47.03	68.79	85.37	114.19	150.45	182.86	212.12
Price 8 cents/kwh	47.03	69.11	88.00	116.57	152.46	184.18	212.40
Environm. Indicators							
SO_2 Em.(10^6Tons): BAU	4.85	6.21	7.90	10.18	13.08	16.20	18.65
Price 6 cents/kwh	4.85	6.36	7.95	10.22	13.10	16.20	18.53
Price 8 cents/kwh	4.85	6.35	8.00	10.26	13.12	16.19	18.39
NO_x Em.(10^6Tons): BAU	1.01	1.13	1.27	1.50	1.79	2.09	2.44
Price 6 cents/kwh	1.01	1.15	1.29	1.52	1.80	2.10	2.45
Price 8 cents/kwh	1.01	1.15	1.31	1.53	1.81	2.11	2.45

It can be seen from Table 5.8 that lower economic activity as a response to higher nuclear energy costs is moderate; the GDP loss induced by a doubling of costs is below 1%. It is furthermore observed that each 2 cent/kwh rise in expected cost postpones the nuclear program by 5 years. Pollutant emissions of increased nuclear cost scenarios remain close to BAU-emissions since there is no significant change in the energy system composition.

To summarise, it is found that the economic impacts of unexpectedly high nuclear prices are moderate in comparison to the huge economic losses resulting from anti-nuclear policies. It is observed that anti-nuclear policies increase the dependence on imported fuels as more imports of oil&gas are required. Solutions point out the importance of nuclear electricity for Turkey. The model calculates that a no-nuclear policy would cost Turkey more than $10 billion annually in GDP loss in 2020 and a staggering $60 billion in 2035. These effects are lessened when nuclear generation costs increase significantly but do not disappear completely. Although the GDP loss is striking, calculations are not unquestionable in view of the limited representativeness of a one-sector model. It is clear however that a more careful analysis of nuclear energy is necessary that takes into account greater detail such as plant size, financing and timing before declaring a ban on nuclear power as Turkey seems to be doing at the present.

5.2.3. Energy Import Price Scenarios

Oil prices can exhibit significant fluctuations depending on Middle East politics and on OPEC production quotas. The reference price of oil assumed in the model is $18/barrel in 1991 dollars and, with an annual growth rate of 2.5%, reaches $22.5/barrel in 2000. Two additional scenarios are defined: the high price scenario assumes an annual 5% growth of oil prices and the low price scenario a 1% growth, both starting from 2000. The results are presented in Table 5.9.

Table 5.9. Model Sensitivity to Variations in Oil Prices

	2005	2010	2015	2020	2025	2030	2035
Economic Indicators							
GDP (10^9 $): BAU	249.94	309.69	380.36	469.85	577.73	710.51	876.12
Low Price 1% growth	250.35	310.82	382.46	473.52	583.83	720.37	889.64
High Price 5% growth	249.16	307.37	375.69	461.35	563.96	690.76	841.79
Investm. (10^9 $): BAU	81.36	94.19	116.05	138.95	164.61	193.84	242.36
Low Price 1% growth	81.78	94.79	117.00	140.85	167.11	198.72	242.33
High Price 5% growth	80.55	92.76	114.11	135.18	161.82	192.10	223.99
Exports (10^9 $): BAU	40.92	51.08	62.97	78.24	96.59	119.27	147.79
Low Price 1% growth	41.02	51.34	63.45	79.08	97.99	121.53	150.90
High Price 5% growth	40.74	50.54	61.89	76.29	93.42	114.73	139.90
Imports (10^9 $): BAU	62.48	77.42	95.09	117.46	144.43	177.63	219.03
Low Price 1% growth	62.59	77.70	95.62	118.38	145.96	180.09	222.41
High Price 5% growth	62.29	76.84	93.92	115.34	140.99	172.69	210.45
Energy Indicators							
Electr. (Twh): BAU	189.61	280.19	377.22	510.66	673.98	887.70	1172.63
Low Price 1% growth	189.92	281.33	379.55	515.37	682.62	902.95	1194.81
High Price 5% growth	188.93	277.55	371.66	499.49	654.75	858.99	1120.97
Oil&Gas (Mtoe): BAU	50.85	53.78	63.52	75.84	91.39	116.80	155.17
Low Price 1% growth	51.58	58.36	69.61	83.84	101.71	129.25	168.23
High Price 5% growth	50.63	50.34	59.74	71.78	87.22	112.63	151.00
Solids (Mtoe): BAU	47.04	65.35	82.57	111.72	148.49	181.66	211.78
Low Price 1% growth	46.86	58.19	75.62	105.71	143.99	180.32	213.49
High Price 5% growth	46.93	71.28	84.80	110.26	141.71	169.13	188.78
Environm. Indicators							
SO_2 Em.(10^6Tons): BAU	4.85	6.21	7.90	10.18	13.08	16.20	18.65
Low Price 1% growth	4.86	5.98	7.70	10.06	13.06	16.35	19.23
High Price 5% growth	4.83	6.43	7.88	10.02	12.72	15.50	16.55
NO_x Em.(10^6Tons): BAU	1.01	1.13	1.27	1.50	1.79	2.09	2.44
Low Price 1% growth	1.02	1.13	1.30	1.58	1.91	2.28	2.66
High Price 5% growth	1.00	1.14	1.27	1.47	1.72	1.99	2.27

It is observed from Table 5.9 that, as might be expected, low oil prices positively affect economic activities, increasing all growth rates and high prices conversely lead to a shrinking of economic activity. A look at energy indicators shows that low oil prices cause increased consumption of oil&gas and high prices lead to a decreased oil&gas consumption. It is interesting to note that the low and high price scenarios both do not lead to significantly higher pollutant emissions. The high price scenario does not cause an increase of emissions because it causes a lowering of economic and energy activities. The low price scenario on the other hand increases energy activities but does not increase emissions because it leads to a shift from solid fuels towards less polluting oil&gas.

The reference price of natural gas taken in the model, 3.76 $\$/10^6$ Btu in 1991, is assumed to grow at an annual rate of 2%. Two additional scenarios are defined to determine the sensitivity of the results to gas prices: the high price scenario assumes an annual 3% growth in prices and the low price scenario assumes a 1% growth, both starting from 2000. Results are presented in Table 5.10. The implications from Table 5.10 are similar to those of Table 5.9. That is, low natural gas prices positively affect economic activities increasing growth rates of economic indicators; and high prices conversely lead to a shrinkage of the economy. Similarly, low gas prices cause an increased consumption of oil&gas and vice versa. The major difference of effects caused by natural gas price change scenarios from those induced by oil price changes is that natural gas price changes more strongly affect energy and economic balances. Due to more pronounced changes, considerable differences arise also in the level of pollutant emissions. It is observed that higher natural gas prices lead in the long run to less emissions and lower prices to more. The high price scenario reduces emissions because it causes a general shrinkage of economic and at the same time of energy activities. The low price scenario on the other hand increases pollutant emissons by the rise in energy activities.

Table 5.10. Model Sensitivity to Variations in Natural Gas Prices

	2005	2010	2015	2020	2025	2030	2035
Economic Indicators							
GDP ($10^9 \$$): BAU	249.94	309.69	380.36	469.85	577.73	710.51	876.12
Low Price 1% growth	250.33	311.10	383.08	474.15	583.83	720.87	893.45
High Price 3% growth	249.40	307.77	376.52	462.83	565.19	687.14	819.54
Investm. ($10^9 \$$): BAU	81.36	94.19	116.05	138.95	164.61	193.84	242.36
Low Price 1% growth	82.39	95.90	117.90	141.29	165.95	201.77	240.71
High Price 3% growth	79.95	91.99	113.17	133.23	156.75	176.58	181.65
Exports ($10^9 \$$): BAU	40.92	51.08	62.97	78.24	96.59	119.27	147.79
Low Price 1% growth	41.01	51.40	63.59	79.23	97.99	121.65	151.78
High Price 3% growth	40.80	50.64	62.08	76.63	93.70	113.89	134.78
Imports ($10^9 \$$): BAU	62.48	77.42	95.09	117.46	144.43	177.63	219.03
Low Price 1% growth	62.58	77.77	95.77	118.54	145.96	180.22	223.36
High Price 3% growth	62.35	76.94	94.13	115.71	141.30	171.78	204.88
Energy Indicators							
Electr. (TWH): BAU	189.61	280.19	377.22	510.66	673.98	887.70	1172.63
Low Price 1% growth	190.07	282.28	381.56	518.49	686.52	910.43	1212.28
High Price 3% growth	188.93	277.18	371.01	498.35	650.99	844.25	1069.67
Oil&Gas (Mtoe): BAU	50.85	53.78	63.52	75.84	91.39	116.80	155.17
Low Price 1% growth	50.93	56.35	66.37	79.10	95.24	121.08	159.45
High Price 3% growth	50.70	53.78	59.40	71.44	86.87	112.29	147.90
Solids (Mtoe): BAU	47.04	65.35	82.57	111.72	148.49	181.66	211.78
Low Price 1% growth	47.05	60.37	78.97	110.53	150.26	189.95	229.09
High Price 3% growth	46.99	62.70	85.94	110.81	140.66	162.97	172.27
Environm. Indicators							
SO_2 Em.(10^6Tons): BAU	4.85	6.21	7.90	10.18	13.08	16.20	18.65
Low Price 1% growth	4.85	6.03	7.77	10.15	13.18	16.55	20.22
High Price 3% growth	4.84	6.11	7.90	10.02	12.65	14.76	14.34
NO_x Em.(10^6Tons): BAU	1.01	1.13	1.27	1.50	1.79	2.09	2.44
Low Price 1% growth	1.01	1.11	1.27	1.52	1.83	2.18	2.59
High Price 3% growth	1.01	1.11	1.28	1.48	1.72	1.96	2.16

5.3. Environmental Scenarios

The scenarios defined in this section aim to reduce pollutant emissions to levels as foreseen by European standards. They are comprised of direct control scenarios, exogenous tax scenarios, an endogenised pollution abatement scenario and an endogenised tax scenario. The direct control scenarios include upper bounds on emissions and so enforce abatement without taxation; they simulate EU regular standards as well as less stringent standards that are likely to be applied to Turkey in early membership years. The tax charges of exogenous tax scenarios are adjusted so that European regulations are satisfied; these scenarios include pollutant and energy taxes as alternative instruments to reduce emissions. The endogenised pollution abatement scenario is also tuned to comply with European regulations. Less stringent emission standards are achieved in the tax endogenised runs.

5.3.1. Direct Control Scenarios

Turkey has not ratified the Kyoto Protocol (1997) which is the most recent international resolution on emission reductions. However, the European Union has signed the protocol and Turkey has applied for full membership to the European Union. Turkey will therefore be asked by the European Union to comply with their emission standards when membership negotiations start. European regulations allow maximum annual emissions of 1.8 Million Tons of NO_x and 2.6 Million Tons of SO_2 (Plinke, 1992). However it is possible that, like in the case of Spain, a transitional arrangement defining less stringent standards will be made in order to allow for a smooth transitory phase. In this respect, two scenarios with varying pollutant emission limits, whose results are summarised in Table 5.11, are defined as follows:

1) Scenario EUR: European Union Regular Standard Scenario; Allowable limits: 1.8 Million Tons NO_x; 2.6 Million Tons SO_2 .

2) Scenario EUE: European Union Extra Allowance Scenario; Allowable limits: 1.8 Million Tons NO_x; 3.4 Million Tons SO_2 until 2010, 3.0 Million Tons from 2010 until 2020, and 2.6 Million Tons thereafter.

Table 5.11. Results of European Union Emission Policies

		2005	2010	2015	2020	2025	2030	2035
Economic Indicators								
GDP (10^9 $):	BAU	249.94	309.69	380.36	469.85	577.73	710.51	876.12
	EUR	249.49	308.66	378.49	466.43	572.81	704.93	868.84
	EUE	249.63	309.00	379.14	467.50	573.29	703.57	864.96
Investm. (10^9 $):	BAU	81.36	94.19	116.05	138.95	164.61	193.84	242.36
	EUR	80.82	93.58	115.08	137.68	164.33	195.36	238.04
	EUE	80.97	93.91	115.75	137.93	162.77	192.18	234.89
Exports (10^9 $):	BAU	40.92	51.08	62.97	78.24	96.59	119.27	147.79
	EUR	40.82	50.84	62.54	77.45	95.46	117.98	146.12
	EUE	40.85	50.92	62.69	77.70	95.57	117.67	145.23
Imports (10^9 $):	BAU	62.48	77.42	95.09	117.46	144.43	177.63	219.03
	EUR	62.37	77.17	94.62	116.61	143.20	176.23	217.21
	EUE	62.41	77.25	94.78	116.87	143.32	175.89	216.24
Energy Indicators								
Electr. (TWH):	BAU	189.61	280.19	377.22	510.66	673.98	887.70	1172.63
	EUR	189.22	278.83	374.60	505.90	666.98	879.68	1161.74
	EUE	189.34	279.29	375.67	507.74	668.37	878.28	1155.93
Oil&Gas (Mtoe):	BAU	50.85	53.78	63.52	75.84	91.39	116.80	155.17
	EUR	50.66	53.34	62.74	74.78	90.22	115.63	154.00
	EUE	50.68	52.51	61.92	73.96	89.40	114.81	153.18
Solids (Mtoe):	BAU	47.04	65.35	82.57	111.72	148.49	181.66	211.78
	EUR	42.88	59.11	75.40	107.98	142.92	174.88	203.83
	EUE	42.96	61.68	78.40	111.54	146.16	176.42	203.33
Environm. Indicators								
SO_2 Em.(10^6Tons):	BAU	4.85	6.21	7.90	10.18	13.08	16.20	18.65
	EUR	2.60	2.60	2.60	2.60	2.60	2.60	2.60
	EUE	3.40	3.40	3.00	3.00	2.60	2.60	2.60
NO_x Em.(10^6Tons):	BAU	1.01	1.13	1.27	1.50	1.79	2.09	2.44
	EUR	0.98	1.09	1.21	1.45	1.72	1.80	1.80
	EUE	0.98	1.10	1.22	1.47	1.74	1.80	1.80

Examination of Table 5.11 shows that emission restrictions cause a shrinkage in economic activity leading to lower GDP, lower investments, lower exports and lower imports. The percentage GDP losses are illustrated in Figure 5.4; the loss induced by regular European emission standards as simulated in scenario EUR increases from 0.2% in 2005 to 0.8% in 2035. It is interesting to note that the GDP loss caused by the looser emission restriction scenario EUE exceeds that of the tighter scenario EUR and reaches 1.3% in 2035 although it is initially lower than that of scenario EUR. This is because the upper emission ceiling is in the long run the same for both scenarios but only the path differs. The economy adjusts itself in the tighter EUR scenario early from initial periods to more stringent standards and the necessity for a less comprehensive adaptation is therefore required in the long run. The 'smooth transitory phase' of scenario EUE on the other hand necessitates more sacrifice from economic growth in order to achieve in the long run the same emission ceiling. The changes in other economic indicators are similar to the change in GDP. The reduction in electricity consumption is initially lower under scenario EUE than under EUR but it is higher in the long run. The same explanation as in the case of economic indicators holds. A look at energy aggregates shows that oil&gas as well as solid fuel use is reduced. However, the oil&gas/solids ratio of emission reduction scenarios changes in favour of oil&gas as evident in Figure 5.5. The ratio is initially highest in scenario EUR since it adapts the energy system early to more stringent emission requirements.

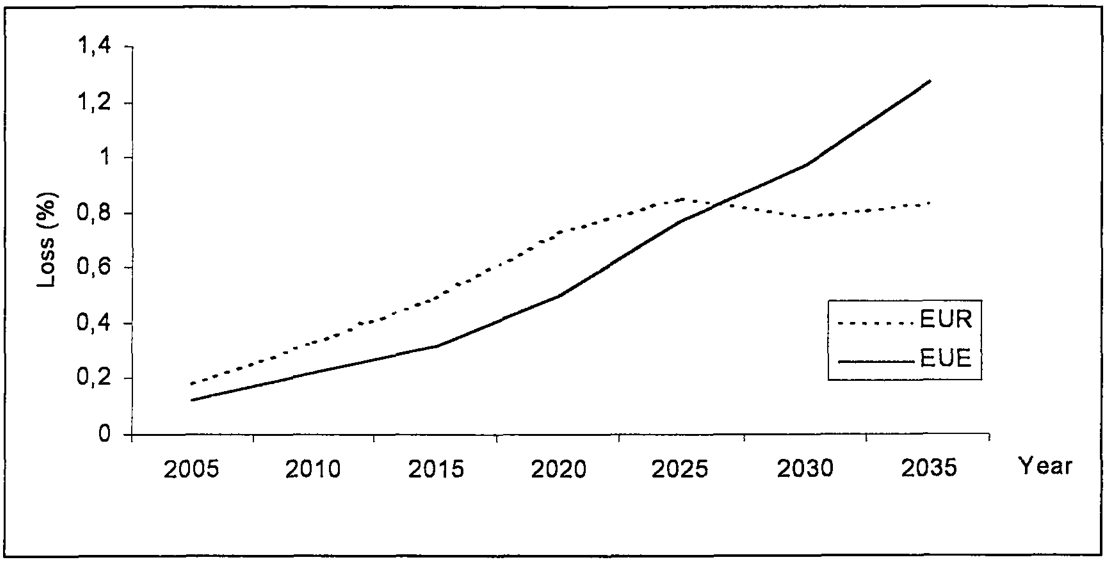

Figure 5.4. Percentage GDP Losses Caused by European Emission Restrictions

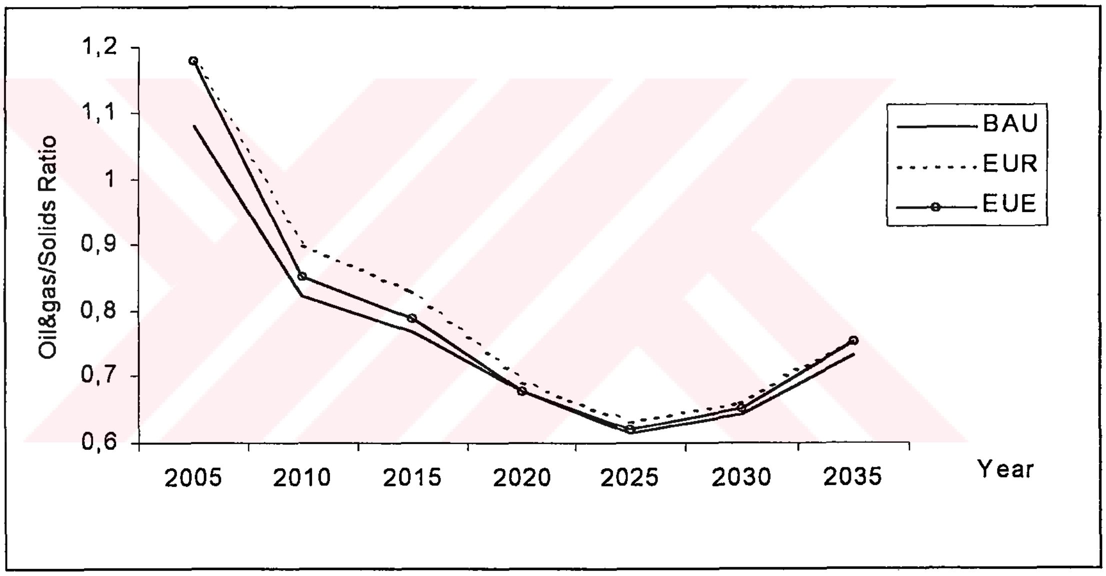

Figure 5.5. Development of Oil&gas/Solids Ratio

Results for nuclear energy are not presented here since emission restrictions do not induce any change in nuclear power consumption. This is because nuclear power capacity is already at its upper bound in the BAU scenario. Therefore a pro-nuclear scenario is defined that extends nuclear power installation limits and the interaction of the pro-nuclear scenario with EU emission restrictions is elaborated in section 5.4.

5.3.2. Exogenous Tax Scenarios

In addition to the BAU scenario, a number of environmental scenarios have been defined that incorporate exogenous taxes as a measure for the reduction of pollutant emissions. Environmental scenarios include either an emission tax that sets a charge on the level of emissions or a sulphur tax that sets a charge on the sulphur content of fuels. Emission taxes are simulated in scenarios S1, S3, N1, N3, S1N1, S3N3 and sulphur taxes are simulated in scenarios SUL1 and SUL3. The definition of scenarios is as follows:

Scenario	Definition
S1 :	100 \$/ton charge on SO_2 emissions
S3 :	300 \$/ton charge on SO_2 emissions
N1 :	100 \$/ton charge on NO_x emissions
N3 :	300 \$/ton charge on NO_x emissions
S1N1 :	100 \$/ton charge on SO_2 and 100 \$/ton charge on NO_x emissions
S3N3 :	300 \$/ton charge on SO_2 and 300 \$/ton charge on NO_x emissions
SUL1 :	100 \$/ton charge on sulphur contained in fuels
SUL3 :	300 \$/ton charge on sulphur contained in fuels

The scenarios are defined so that charges are first applied in year 2005. The amount of tax is adjusted so that high-tax scenarios reduce emissions to satisfy European regulations which allow maximum annual emissions of 1.8 Million Tons of NO_x and 2.6 Million Tons of SO_2 (Plinke, 1992). In the case of SO_2 this corresponds to an approximate 8% emission reduction from the current level. The level of defined emission taxes is in accordance with Sit's findings (Sit, 1994) who has revealed in his investigation of nine different models that, in order to achieve 20% emission reduction until 2020, a charge in the range of 81-370 $/ton is required. Sit's investigation corresponds to the results of models employed by the Energy Modelling Forum at Stanford University using US data.

Results of main economic indicators are summarised in Table 5.12. Year 2000 environmental scenario results are not included in the table since they do not significantly differ from BAU results (the highest variations are within a tolerance limit of 0.01%) – this is not surprising since environmental taxes are applied in year 2005 first. It can be seen from Table 5.12 that environmental scenarios cause, in comparison to the BAU scenario, a loss in GDP. The highest GDP losses occur when sulphur tax is applied; a maximum loss of 1.3% occurs in 2020. It is interesting to note that in general investments are reduced in initial years whereas they increase in the long term. The short-term decline in investments can be explained by a general shrinkage of the economy, the long-term increase on the other hand is a result of costly abatement investments as well as more expensive energy investments into cleaner energy technologies. It is found that in spite of economic shrinkage, environmental scenarios do not significantly decrease foreign trade activities. This is due to the increased need to import abatement technologies as well as cleaner fuels into the country. Exports on the other hand generate foreign exchange and finance the rise in import demand; hence, no environmental scenario significantly affects the gap between exports and imports. The last column in Table

5.12 shows that environmental scenarios do not significantly alter the debt/GDP ratio. It must be stated however that the stability of the foreign exchange gap is actually due to model constraints that limit exports and imports to a fraction of GDP in order to prevent large fluctuations.

Table 5.12. Results of ENVEES: Main Economic Indicators (10^9 \$)

	GDP	Investm.	Exports	Imports	For. Debt	Debt/GDP
2000 *BAU*	*200.90*	*59.51*	*30.99*	*48.62*	*77.19*	*0.384*
2010 *BAU*	*309.69*	*94.19*	*51.08*	*77.42*	*127.72*	*0.412*
S1	308.74	93.79	50.86	77.18	127.62	0.413
S3	308.08	93.26	50.71	77.02	127.54	0.414
N1	309.52	94.13	51.04	77.38	127.70	0.413
N3	309.18	93.97	50.96	77.30	127.66	0.413
S1N1	308.55	93.73	50.82	77.14	127.59	0.414
S3N3	307.56	93.05	50.59	76.89	127.48	0.414
SUL1	308.04	93.11	50.70	77.01	127.54	0.414
SUL3	307.34	92.45	50.54	76.84	127.48	0.415
2020 *BAU*	*469.85*	*138.95*	*78.24*	*117.46*	*204.73*	*0.436*
S1	468.04	139.19	77.82	117.01	204.35	0.437
S3	466.23	139.12	77.41	116.56	204.03	0.438
N1	469.63	139.03	78.19	117.41	204.67	0.436
N3	469.06	138.99	78.06	117.26	204.54	0.436
S1N1	467.76	139.21	77.76	116.94	204.28	0.437
S3N3	465.32	138.93	77.20	116.33	203.83	0.438
SUL1	465.91	139.45	77.33	116.48	203.99	0.438
SUL3	463.87	138.86	76.86	115.97	203.65	0.439
2030 *BAU*	*710.51*	*193.84*	*119.27*	*177.63*	*321.52*	*0.453*
S1	709.85	196.21	119.12	177.46	320.86	0.452
S3	709.67	201.06	119.07	177.42	320.25	0.451
N1	710.53	194.17	119.29	177.66	321.44	0.452
N3	710.30	194.85	119.22	177.57	321.21	0.452
S1N1	709.79	196.67	119.10	177.45	320.75	0.452
S3N3	708.69	201.41	118.85	177.17	319.85	0.451
SUL1	710.23	203.59	119.13	177.52	320.28	0.451
SUL3	709.78	205.71	118.89	177.26	319.58	0.450

The composition of primary energy is given in Table 5.13. It can be seen from this table that environmental taxes discourage the use of lignites. The decline in lignites is most pronounced in sulphur tax scenarios – it is 25% in 2010 and declines to 7% in 2030. It is observed that all environmental scenarios drastically reduce lignite consumption in the short term but recover in the long run. This is because energy alternatives and hence substitution possibilities get limited in the long run and it becomes necessary to even exploit the 'dirty' domestic energy reserves and install abatement technologies to 'clean' them. Parallel to these energy system changes, the oil&gas ratio increases initially as a result of environmental taxation but reduces to BAU-levels in the long run.

Table 5.13. Results of ENVEES: Primary Energy Composition (Mtoe)

	Nat. gas	Hardcoal	Lignite	Oil	Total	Oil&gas/solids
2000 *BAU*	*15.03*	*11.85*	*20.63*	*35.89*	83.40	*1.57*
2010 *BAU*	17.87	14.11	51.24	35.91	119.13	0.82
S1	18.36	13.91	44.44	35.79	112.50	0.93
S3	20.14	13.71	39.36	35.59	108.80	1.05
N1	17.96	14.11	50.97	35.82	118.86	0.83
N3	18.09	14.10	50.50	35.65	118.34	0.83
S1N1	18.51	13.90	43.95	35.70	112.06	0.94
S3N3	20.05	13.71	39.36	35.39	108.51	1.04
SUL1	21.16	13.71	39.35	35.51	109.73	1.07
SUL3	22.24	13.71	38.58	35.31	109.84	1.10
2020 *BAU*	39.32	21.26	90.46	36.53	187.57	0.68
S1	39.80	20.90	88.25	36.37	185.32	0.70
S3	41.59	20.36	81.97	36.02	179.94	0.76
N1	39.40	21.25	90.13	36.40	187.18	0.68
N3	39.54	21.22	89.40	36.15	186.31	0.68
S1N1	39.96	20.88	87.67	36.24	184.75	0.70
S3N3	41.50	20.34	81.62	35.71	179.17	0.76
SUL1	42.60	20.35	79.24	35.87	178.06	0.79
SUL3	43.69	19.73	75.74	35.50	174.66	0.83
2030 *BAU*	80.17	38.48	143.18	36.64	298.47	0.64
S1	80.65	38.15	142.28	36.53	297.61	0.65
S3	82.44	37.47	137.07	36.20	293.18	0.68
N1	80.25	38.48	143.17	36.52	298.42	0.64
N3	80.39	38.46	142.65	36.26	297.76	0.64
S1N1	80.81	38.14	141.90	36.41	297.26	0.65
S3N3	82.35	37.44	136.65	35.87	292.31	0.68
SUL1	83.45	37.64	136.38	36.10	293.57	0.69
SUL3	84.54	36.89	132.94	35.72	290.09	0.71

Table 5.14. Results of ENVEES: Electric Energy Composition (Twh)

	Hydro	Nat. gas	H.coal	Lignite	Oil	Nuclear	Total
2000 *BAU*	*48.83*	*33.98*	*3.07*	*33.38*	*8.24*	*0*	127.50
2010 *BAU*	117.83	46.94	3.00	98.70	6.71	*7.00*	162.43
S1	126.78	49.16	3.00	86.66	6.71	7.00	279.31
S3	126.78	57.30	3.00	77.69	6.71	7.00	278.48
N1	117.80	47.34	3.00	98.22	6.71	7.00	280.07
N3	117.73	47.96	3.00	97.40	6.71	7.00	279.80
S1N1	126.78	49.87	3.00	85.81	6.71	7.00	279.17
S3N3	126.78	56.89	3.00	77.69	6.71	7.00	278.07
SUL1	122.27	61.93	3.00	77.67	6.71	7.00	278.58
SUL3	122.57	64.32	3.00	74.30	6.71	7.00	277.90
2020 *BAU*	141.66	144.74	13.51	180.17	5.18	*25.40*	510.66
S1	141.66	146.97	13.51	176.26	5.18	25.40	508.98
S3	141.66	155.10	13.51	165.15	5.18	25.40	506.00
N1	141.66	145.14	13.51	179.58	5.18	25.40	510.47
N3	141.66	145.77	13.51	178.29	5.18	25.40	509.81
S1N1	141.66	147.67	13.51	175.23	5.18	25.40	508.65
S3N3	141.66	154.69	13.51	164.54	5.18	25.40	504.98
SUL1	141.66	159.73	13.51	160.33	5.18	25.40	505.81
SUL3	141.66	164.12	12.45	154.13	5.18	25.40	502.94
2030 *BAU*	141.66	331.05	50.71	293.13	3.65	*67.50*	887.70
S1	141.66	333.27	50.71	291.54	3.65	67.50	888.33
S3	141.66	341.40	50.71	282.31	3.65	67.50	887.23
N1	141.66	331.44	50.71	293.11	3.65	67.50	888.07
N3	141.66	332.07	50.71	292.19	3.65	67.50	887.78
S1N1	141.66	333.98	50.71	290.86	3.65	67.50	888.36
S3N3	141.66	341.00	50.71	281.57	3.65	67.50	886.09
SUL1	141.66	346.04	50.71	281.09	3.65	67.50	890.65
SUL3	141.66	350.42	49.66	275.01	3.65	67.50	887.89

Table 5.14 presents the composition of electric energy. Again, a shift away from lignites is observed in the short run which is most pronounced in sulphur tax applications and partly recovered in the long run. The electricity generated by oil fired power plants is not affected by environmental taxation since existing plants using oil are retired and no new plants of this type are installed in the BAU projections and in environmental scenario results. It can be seen that there is also no change in the amount of electricity produced by hardcoal, hydro sources and nuclear fuels. This is because these fuels are already utilised at their upper bounds in the BAU scenario. However their percentage in electricity generation increases

due to the decline in total electricity generation. Results of a pro-nuclear scenario in which nuclear power bounds are extended are elaborated in section 5.4.

Table 5.15 presents BAU-emissions with respect to their source and their share in total emissions.

Table 5.15. Breakdown of BAU-Emissions According to Source (10^6 Tons)

	Lignite	Oil	Hardcoal	Nat. gas	Total
2000 SO_2 - Electric	1.614 (56%)	0.028 (1%)	0.007 (0.2%)	0.022 (0.8%)	1.671
SO_2 - Nonel.	0.287 (10%)	0.544 (19%)	0.309 (11%)	0.059 (2%)	1.199
NO_x –Electric	0.100 (11%)	0.019 (2%)	0.010 (1%)	0.018 (2%)	0.147
NO_x –Nonel.	0.023 (3%)	0.632 (70%)	0.069 (8%)	0.031 (3%)	0.755
2010 SO_2 - Electric	4.880 (78%)	0.023 (0.4%)	0.007 (0.1%)	0.030 (0.5%)	4.940
SO_2 - Nonel.	0.287 (5%)	0.553 (9%)	0.375 (6%)	0.059 (1%)	1.274
NO_x –Electric	0.297 (26%)	0.016 (1%)	0.010 (0.9%)	0.025 (2%)	0.348
NO_x –Nonel.	0.023 (2%)	0.643 (57%)	0.084 (7%)	0.031 (3%)	0.781
2020 SO_2 - Electric	8.652 (85%)	0.018 (0.2%)	0.032 (0.3%)	0.092 (1%)	8.794
SO_2 - Nonel.	0.287 (3%)	0.573 (6%)	0.469 (5%)	0.059 (0.6%)	1.388
NO_x –Electric	0.542 (36%)	0.012 (0.8%)	0.043 (3%)	0.078 (5%)	0.675
NO_x –Nonel.	0.023 (2%)	0.667 (44%)	0.105 (7%)	0.031 (2%)	0.826
2030 SO_2 - Electric	14.361(89%)	0.012 (0.1%)	0.120 (0.7%)	0.211 (1%)	14.704
SO_2 - Nonel.	0.287 (2%)	0.585 (4%)	0.567 (4%)	0.059 (0.4%)	1.498
NO_x –Electric	0.882 (42%)	0.009 (0.4%)	0.162 (8%)	0.179 (9%)	1.232
NO_x –Nonel.	0.023 (1%)	0.680 (32%)	0.127 (6%)	0.031 (1%)	0.861

It is evident from the above table that lignite-fired power plants initially contribute to 56% of total SO_2 emissions gradually increasing to 89% in 2030. They are also, after oil products, the second-largest contributor to NO_x emissions. The nonelectric use of oil contributes initially to 70% of total NO_x emissions gradually decreasing to 32% in 2030. The share of NO_x emissions emitted by lignite-fired power plants on the other hand increases from 11% in 2000 to 42% in 2030. The effects of SO_2 emission taxes as well as sulphur taxes on SO_2 emissions can be seen in Figure 5.6. It can be seen from this figure that both emission tax scenarios lead to less SO_2 emissions than the two sulphur tax scenarios.

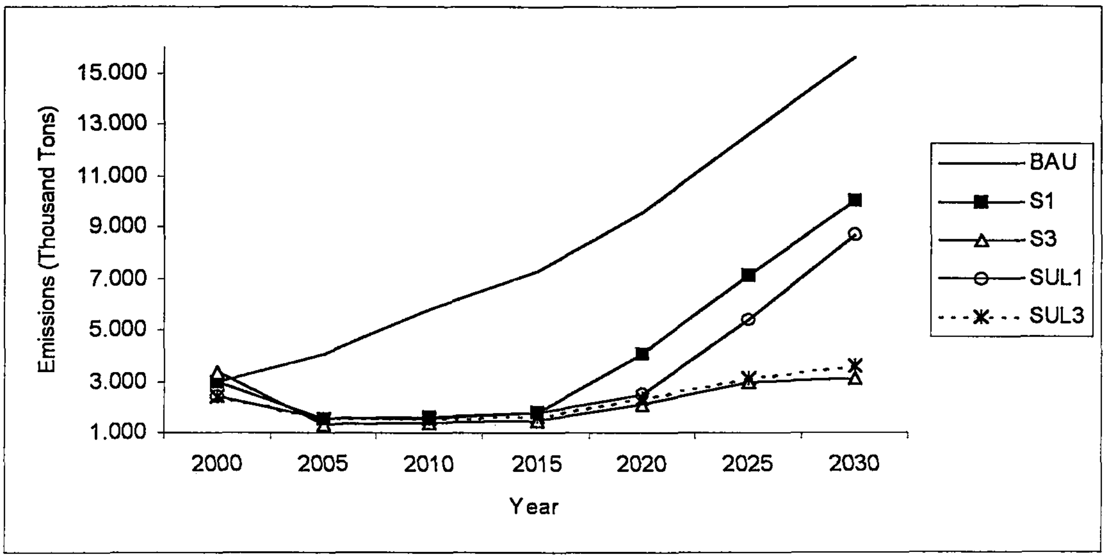

Figure 5.6. Development of SO_2 Emissions

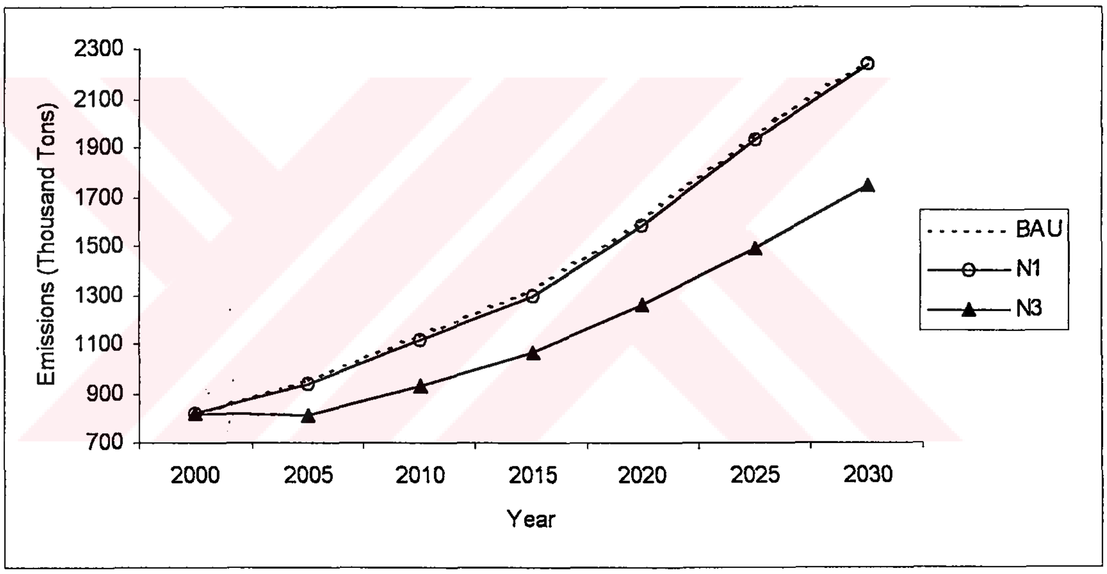

Figure 5.7. Development of NO_x Emissions

Figure 5.7 depicts the effects of NO_x emission taxes on NO_x emissions. It can be seen from the figure that the reduction of NO_x emissions achieved by the two emission tax scenarios N1 and N3 is quite limited. In any case there is no need for a significant reduction of NO_x emissions because NO_x emissions in the BAU scenario remain in the next twenty years below the 1.8 million ton/year limit set by European standards. SO_2 emissions on the other hand start to exceed the annual 2.6 million ton limit in initial periods.

Table 5.16 presents the emission intensity EMI and energy intensity ENI defined in accordance with Sit's (1994) proposal (EMI = total emissions / total primary energy consumed; ENI = total primary energy consumed / GDP).

Table 5.16. Results of ENVEES: Emission and Energy Intensities
(EMI: Ton/Toe ; ENI: Toe/100$)

	BAU	S1	S3	N1	N3	S1N1	S3N3	SUL1	SUL3
2000 EMI	0.048	0.048	0.053	0.049	0.049	0.048	0.053	0.041	0.041
ENI	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039
2010 EMI	0.058	0.023	0.021	0.058	0.056	0.023	0.030	0.031	0.031
ENI	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.035	0.035
2020 EMI	0.059	0.030	0.020	0.059	0.057	0.030	0.018	0.038	0.031
ENI	0.041	0.041	0.041	0.041	0.041	0.041	0.041	0.041	0.040
2030 EMI	0.059	0.041	0.018	0.059	0.057	0.041	0.016	0.053	0.048
ENI	0.044	0.044	0.044	0.044	0.044	0.044	0.044	0.044	0.043

It can be seen from the above table that in the base case EMI and ENI grow between 2000 and 2030 at an average annual rate of 0.7% and 0.4% respectively. This is a typical indicator of the growing and industrialising economic situation in Turkey. In industrialised countries both rates usually decline in reference path scenarios. In 1998, the energy intensities of Australia, France, Germany, Portugal, Spain, Switzerland, United States and United Kingdom have respectively been 0.027, 0.019, 0.018, 0.026, 0.019, 0.011, 0.031 and 0.022 Toe/100$ according to International Energy Agency Statistics. This means that the energy intensity of the Turkish economy is higher than that of EU countries; it is an indicator of the low energy efficiency of the economy. There appears to be no significant effect of environmental charges on the energy intensity which means that there is no indication of a shift from or to energy intensive industries. It can be seen that environmental scenario results cause a decline in the emission intensity which is a desired effect. The reduction in EMI reflects more intensive use of less polluting energy sources.

More significant for Turkey is to question the economic implications of environmental concern. Although abatement costs are explicitly calculated in the model, the secondary effects of environmental policies in the longer run can be more important The model provides an indication of these effects in the various economic series such as the GDP growth path under different abatement policies. The marginal abatement costs of sulphur and SO_2 emission tax scenarios, computed as the GDP losses per unit emission reduced with respect to the BAU scenario, are plotted in Figure 5.8.

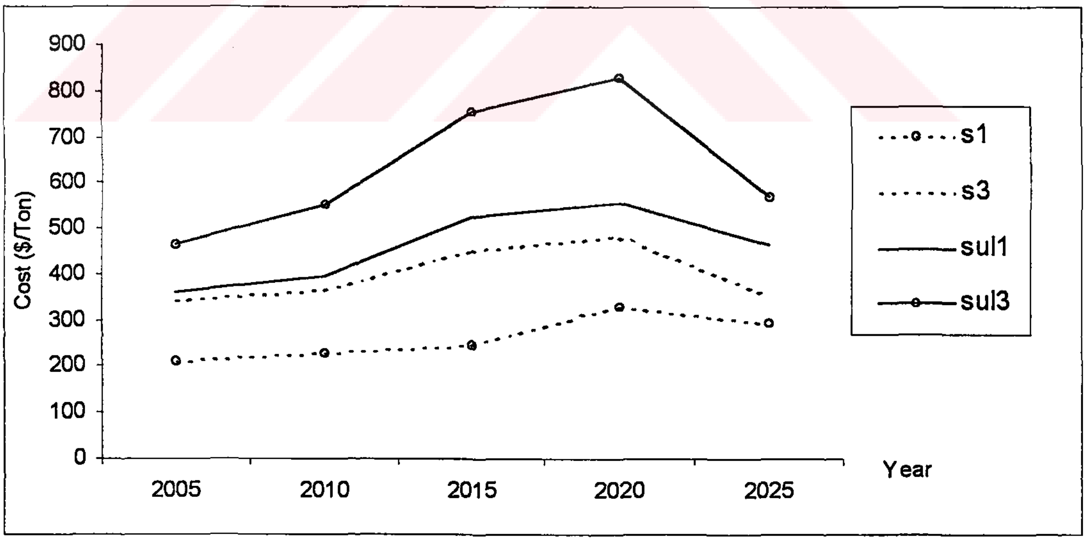

Figure 5.8. Marginal Abatement Costs of SO_2 Emission and Sulphur Tax Scenarios

It is observed from the above figure that the marginal abatement costs of sulphur tax scenarios are higher than those of SO_2 emission tax scenarios. In other words, one unit SO_2 reduction implies more decline in GDP growth when achieved by sulphur taxation instead of emission taxation. Accordingly, it is concluded that a tax on SO_2 emissions is more effective in reducing SO_2 emissions than a tax applied on the sulphur content of fuels.

5.3.3. Endogenised Pollution Abatement Scenario

Endogenised pollution abatement results are obtained with a quality-of-life penalty function integrated model specification that incorporates a preference rate, which is related to the level of pollutant emissions, into the utility function as described in section 4.2.2. Solutions are summarised in Table 5.17.

Table 5.17. Summary Results from the Abatement Endogenised Model

	2000	2005	2010	2015	2020	2025	2030
SO_2 Emissions (10^6Tons)	1.522	1.403	1.440	1.749	2.497	5.417	8.665
NO_x Emissions (10^6Tons)	0.903	0.977	1.065	1.199	1.451	1.741	2.065
Total Emissions	2.425	2.380	2.505	2.948	3.948	7.158	10.730
GDP (10^9 \$)	200.81	249.47	308.72	378.61	467.44	576.34	710.18
Electricity (Twh)	127.45	189.24	278.80	374.50	506.89	671.21	887.26
Oil&Gas (Mtoe)	50.92	50.74	55.85	65.49	77.79	93.45	118.86
Solids (Mtoe)	32.47	42.81	53.09	69.33	102.77	140.02	176.46

Results are satisfactory in the sense that emissions remain within the levels implied by European Union regulations until 2020 and thereafter only slightly exceed them; GDP losses remain below 0.6% until 2030. The results obtained with the abatement endogenised version of ENVEES will not be discussed in more detail since this version only represents a transition to the tax-endogenised specification.

5.3.4. Endogenised Tax Scenario

Results of the endogenised tax scenario are obtained with the model specification described in section 4.2.3. This time, the incorporated preference rate is related both to the level of emission tax and to pollutant emissions. Solutions are summarised in Table 5.18.

Table 5.18. Summary Results from the Endogenous Tax Model

	2000	2005	2010	2015	2020	2025	2030
SO_2 Emissions (10^6Tons)	2.864	1.546	4.679	5.998	7.985	12.395	15.870
NO_x Emissions (10^6Tons)	0.903	0.972	1.085	1.222	1.486	1.767	2.082
Total Emissions	3.767	2.518	5.764	7.220	9.471	14.162	17.952
GDP (10^9 $)	200.89	247.16	308.50	379.05	468.18	577.48	710.26
Electricity (Twh)	127.43	189.05	278.44	374.34	507.08	671.69	888.13
Oil&Gas (Mtoe)	50.92	50.75	55.81	65.48	77.81	93.49	118.90
Solids (Mtoe)	32.47	41.97	56.13	74.55	108.76	145.27	178.97
Tax ($/Ton SO_2)	0	146.01	76.21	52.44	36.38	27.23	21.71

It can be seen from the above table that the tax charge computed by the model begins with 146.01 $/ton SO_2 in 2005 and gradually falls down to 21.71 $/ton by year 2030. Scenario S1 applies an emission charge which is approximately the average of the tax rate computed by the tax-endogenous version. However, results of scenario S1 are not comparable with the endogenous tax results due to the difference in the mathematical specification of the tax endogenising objective function. A new scenario is therefore defined that exogenously applies the tax rate suggested by the tax-endogenous model. This scenario with decreasing SO_2 emission charges is called SDECEX; it exogenously incorporates 146.01, 76.21, 52.44, 36.38, 27.23, 21.71, 18.69 $/ton charge on SO_2 emissions in years 2005, 2010, 2015, 2020, 2025, 2030 and 2035 respectively. Results of scenarios S1 and

SDECEX are summarised in Table 5.19 together with tax-endogenous model results called SENDOG.

Table 5.19. Summary of ENVEES Scenario S1, SDECEX and SENDOG Results

	2000	2005	2010	2015	2020	2025	2030
SO_2 Em. (10^6Tons) S1	2.864	1.551	3.212	4.880	7.354	10.261	13.428
SDECEX	2.864	1.539	4.727	6.055	8.001	12.415	15.980
SENDOG	2.864	1.546	4.679	5.998	7.985	12.395	15.870
NO_x Em. (10^6Tons) S1	0.903	0.979	1.091	1.230	1.486	1.773	2.085
SDECEX	0.903	0.974	1.090	1.231	1.489	1.778	2.091
SENDOG	0.903	0.972	1.085	1.222	1.486	1.767	2.082
GDP (10^9 \$) S1	200.89	249.41	308.74	379.01	468.04	576.10	709.85
SDECEX	200.89	247.76	308.81	379.54	469.09	577.63	710.50
SENDOG	200.89	247.16	308.50	379.05	468.18	577.48	710.26
Electricity (Twh) S1	127.47	189.35	279.32	375.82	508.97	672.71	888.33
SDECEX	127.47	189.32	279.37	376.23	509.82	673.98	888.74
SENDOG	127.43	189.05	278.44	374.34	507.08	671.69	888.13
Oil&Gas (Mtoe) S1	50.92	50.80	54.14	63.85	76.17	91.77	117.19
SDECEX	50.92	50.81	54.39	64.12	76.47	92.09	117.50
SENDOG	50.92	50.75	55.81	65.48	77.81	93.49	118.90
Solids (Mtoe) S1	32.47	42.96	58.34	75.17	109.15	146.11	180.43
SDECEX	32.47	42.18	57.91	75.01	109.29	146.55	180.99
SENDOG	32.47	41.97	56.13	74.55	108.76	145.27	178.97
Tax (\$/Ton SO_2) S1	0	100	100	100	100	100	100
SDECEX	0	146.01	76.21	52.44	36.38	27.23	21.71
SENDOG	0	146.01	76.21	52.44	36.38	27.23	21.71

It is observed from the above table that SDECEX and SENDOG results are quite close to each other pointing out the validity of the tax-endogenised model. It can further be seen from the table that scenario S1 has the lowest GDP while it achieves the highest emission reduction. It is necessary to compare the marginal abatement costs of the scenarios in order to draw conclusions about their effectiveness in reducing emissions. The scenarios' marginal abatement costs, computed as the GDP losses per unit SO_2 emission reduced, are plotted in Figure 5.9. It is observed from the figure that the marginal abatement costs of scenarios SDECEX and SENDOG are significantly higher than that of scenario S1. In other words, one unit SO_2 reduction implies more decline in GDP growth when achieved by a gradually decreasing tax policy instead of a constant one. Accordingly, it is concluded that a constant tax policy is more effective in reducing SO_2 emissions than a gradually decreasing one.

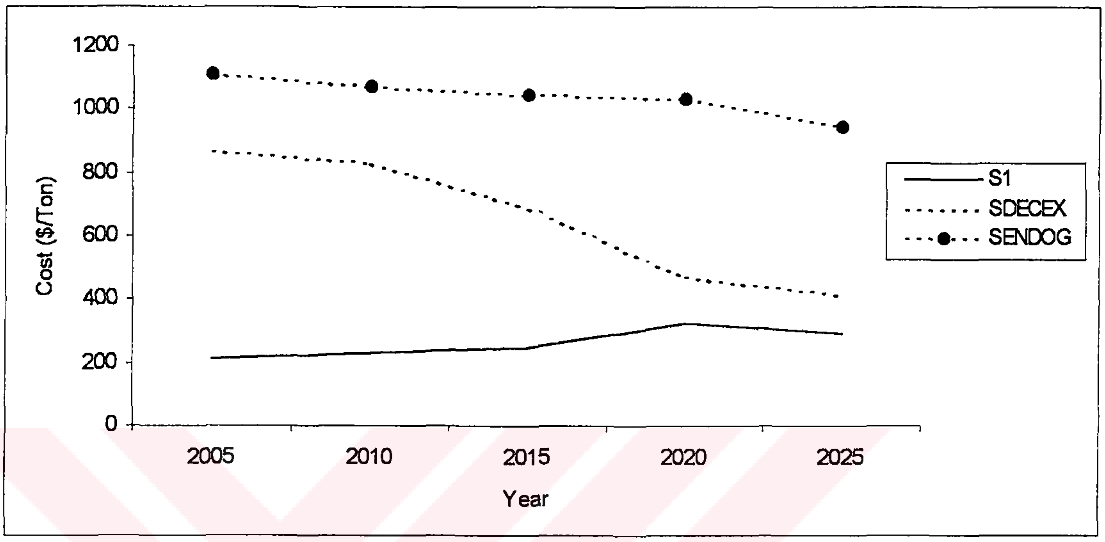

Figure 5.9. Marginal SO_2 Abatement Costs of Constant and Varying Tax Policies

5.4. Scenario Interactions

The interaction of environmental policies with energy decisions is discussed in this section. Scenario interactions that emerge from previous results include the combination of anti-nuclear scenarios with EU emission standards and changing energy price assumptions. In addition, a pro-nuclear scenario is defined that raises nuclear power capacity limits in order to explore the impact of EU emission limits and differing energy price assumptions on nuclear power policies.

5.4.1. Interaction of Nuclear Policies with Emission Restrictions

This section elaborates the economic implications of various nuclear policies under EU pollutant emission retrictions. In order to explore the interaction of various nuclear policies with emission restrictions, five scenarios are defined as follows:

Scenario	Definition
RNEUL	Restricted nuclear policy with EU emission limits
NNEUL	No nuclear policy with EU emission limits
EN	Expanded nuclear policy without any emission limits
ENEUL	Expanded nuclear policy with EU emission limits
ENS3	Expanded nuclear policy with 300 \$/Ton SO_2 Emission Tax

It has already been discussed in section 5.2.1 that anti-nuclear scenarios can cause considerable economic losses. Similar economic losses of anti-nuclear scenarios are incurred under European emission restrictions as shown in Figure 5.10. The figure illustrates GDP effects through an index which is computed by assuming a unitary value for BAU-GDP. It is observed from this figure that the GDP losses of European emission restrictions are quite limited under reference nuclear power assumptions (scenario EUR) whereas nuclear restricting policies significantly decrease the GDP index with respect to BAU results. It is also observed that a pro-nuclear policy with expanded nuclear capacity is capable of increasing GDP from its BAU level while satisfying European emission standards.

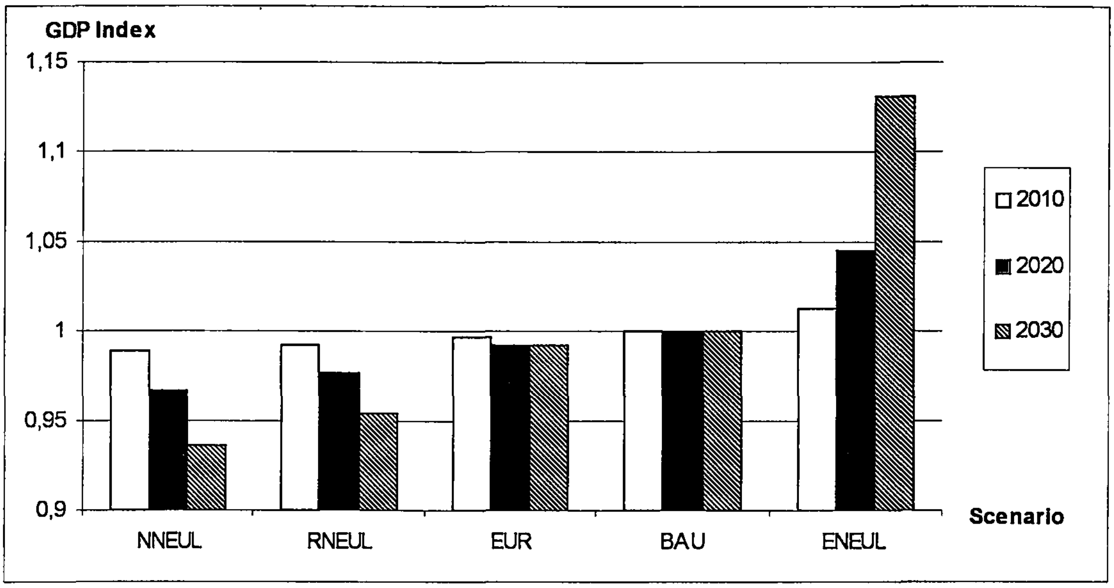

Figure 5.10. GDP Effects of Anti-Nuclear Scenarios under Emission Restrictions

The marginal abatement costs of anti-nuclear scenarios under emission restrictions are plotted in Figure 5.11 as the loss in GDP required to reduce one unit of pollutant from its BAU levels.

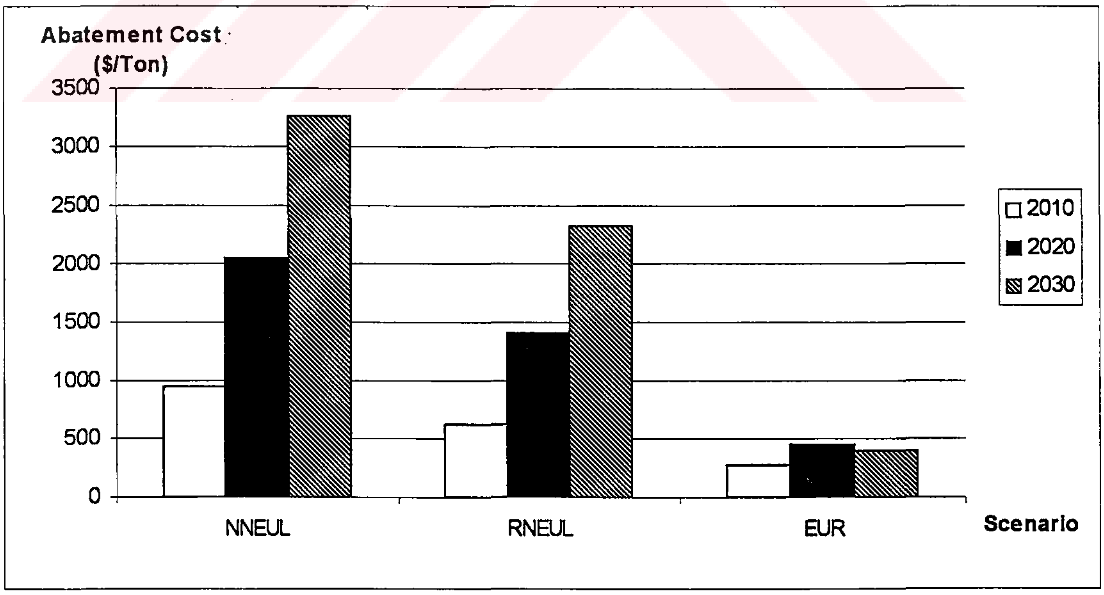

Figure 5.11. Marginal Abatement Costs of Anti-Nuclear Scenarios under Emission Restrictions

In accordance with the previous findings it can be seen from Figure 5.11 that nuclear energy restricting policies inflate the marginal abatement costs. The abatement cost of a no-nuclear policy in terms of GDP loss is approximately twice as much as it is in the case of a standard nuclear policy under reference nuclear power assumptions (scenario EUR); in the case of a restricted nuclear policy these costs are almost 60% higher. The findings reveal the importance of nuclear energy for pollution reduction. It is found that, in addition to the significant economic losses implied by anti-nuclear policies, the cost of reducing pollutant emissions significantly increases when anti-nuclear policies are followed.

As already mentioned, pro-nuclear scenarios and their interaction with emission standards imply economic gains in spite of emission restrictions. The GDP gains of the pro-nuclear scenarios are illustrated Figure 5.12 as a percentage of BAU-GDP.

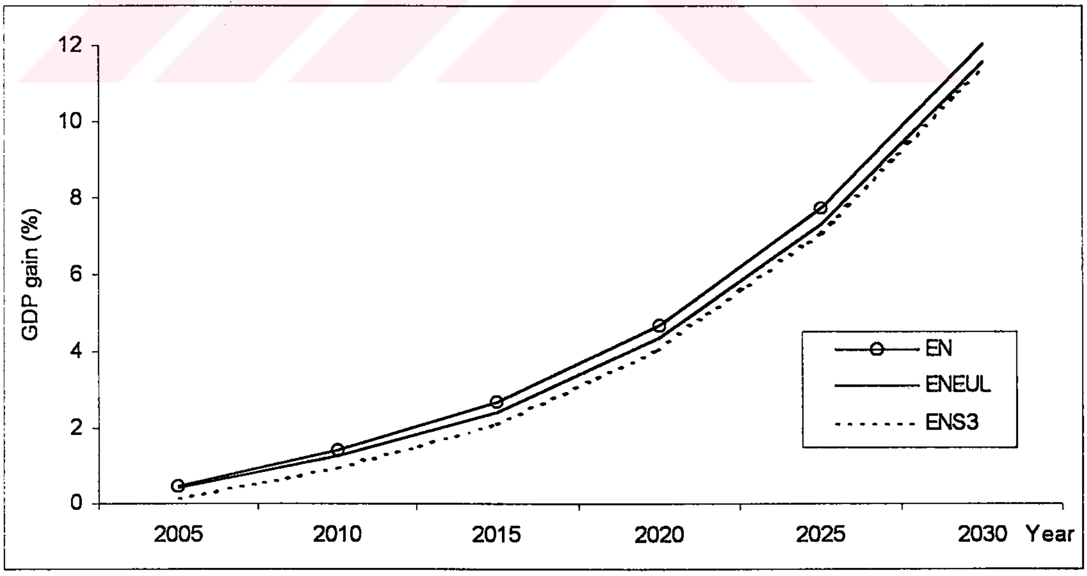

Figure 5.12. GDP Gains from Expanded Nuclear Policies

It is observed from Figure 5.12 that the increase in GDP reaches 11-12% of GDP in 2030 which corresponds to approximately 90-100 billion dollars. There is no observable difference between the GDP gain implied under direct control and emission taxation. It is further observed from Figure 5.11 that the economic losses implied by emission restrictions are quite limited in pro-nuclear scenarios. This is because marginal abatement costs are lower as has already been observed from Figure 5.11.

5.4.2. Interaction of Nuclear Policies with Imported Fuel Prices

This section elaborates the economic implications of various nuclear policies under differing price paths for imported fuels. In order to explore the interaction of various nuclear policies with energy price assumptions, the 'low' and 'high' fuel price assumptions from section 5.2.3 are used. The high price scenario assumes an annual 3% and 5% growth of gas and oil prices respectively whereas the low price scenario assumes a 1% growth of both. Eight scenarios are defined as follows:

Scenario	Definition
RNLPP	Restricted nuclear policy with low oil prices
RNHPP	Restricted nuclear policy with high oil prices
RNLGP	Restricted nuclear policy with low natural gas prices
RNHGP	Restricted nuclear policy with high natural gas prices
ENLPP	Expanded nuclear policy with low oil prices
ENHPP	Expanded nuclear policy with high oil prices
ENLGP	Expanded nuclear policy with low natural gas prices
ENHGP	Expanded nuclear policy with high natural gas prices

The interaction of anti-nuclear scenarios with differing energy import price assumptions reveals the importance of imported fuel prices. The GDP effects of anti-nuclear and expanded nuclear policies are illustrated respectively in Figures 5.13 and 5.14 as the percentage deviation from BAU levels under differing imported fuel price assumptions. It can be observed from Figure 5.13 that higher fuel prices increase the GDP loss of anti-nuclear policies whereas lower prices decrease the loss in GDP. Similarly, higher fuel prices decrease the GDP gain of expanded nuclear policies whereas lower prices increase the gain in GDP as illustrated in Figure 5.14. It can be seen from a comparison of figures 5.13 and 5.14 that the GDP effects of differing fuel price trajectories are higher in the case of anti-nuclear policies. This occurs because anti-nuclear policies increase dependency on fuel imports so that the economy becomes more sensitive to price variations.

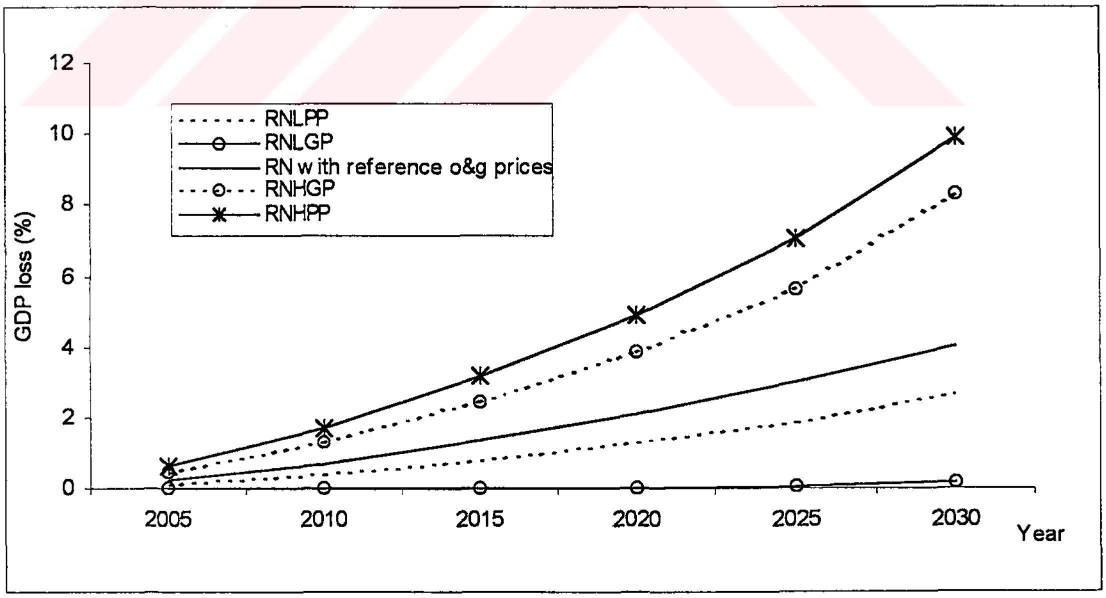

Figure 5.13. GDP Losses of Anti-Nuclear Policies under Differing Energy Prices

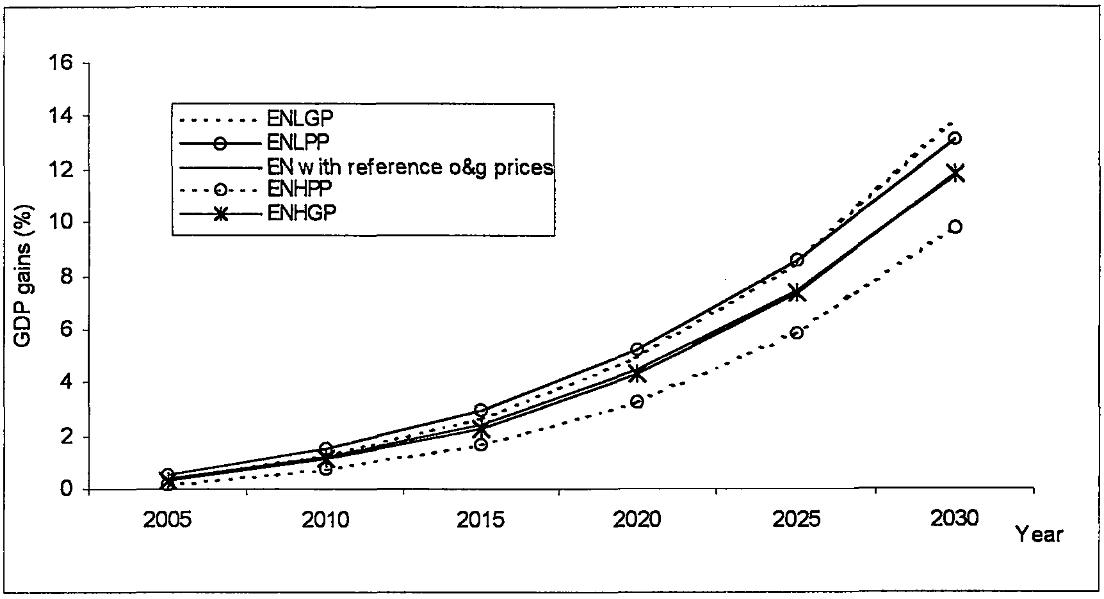

Figure 5.14. GDP Gains from Expanded Nuclear Policies under Differing Energy Prices

To summarise, it is found from the scenario interactions that an anti-nuclear policy, which causes significant economic losses even without any emission limits, considerably increases the cost of reducing pollutant emissions to European levels. Thus, if Turkey should reduce its pollutant emissions to comply with European standards, it would have to suffer considerable economic losses from anti-nuclear policies. This economic loss is only compensated when there is a sufficient reduction in the prices of alternative energy sources. It has been found that anti-nuclear policies increase Turkey's dependence on fuel imports so that the Turkish economy will be more sensitive to imported energy price movements. Thus, lower oil&gas prices can drastically reduce the economic burden of anti-nuclear policies whereas higher prices can easily lead to an economic crisis. Pro-nuclear policies with stronger nuclear engagement on the other hand are found to accelerate economic growth. It is found that even the economic loss implied by EU emission restrictions is limited in the case of increased nuclear power installation. Moreover, policies with expanded nuclear capacity decrease the countries dependency on fuel imports. In short it can be said that all findings from model results of interacting scenarios point out the high importance of nuclear energy for Turkey.

CHAPTER VI

CONCLUSIONS

A systems model of interactions between the energy sector and the rest of the economy is developed in this research where the economy is represented by an aggregate production function in which capital, labour and different energy forms are intermediate inputs to determine GDP. Energy, economy and environmental submodels are linked in such a way that the combined model allows for feedback effects, both from the energy sector and the environment to the economy as well as from the economy to the energy sector and environment. The model constitutes a consistent framework for the elaboration of interdependencies between energy policies, the economy, and the environment and is suitable for making a range of policy analyses for Turkey. Differing model specifications are developed aiming to endogenise pollution abatement and environmental taxes. One such specification incorporates the adverse effects of pollution in the utility function as an alternative way of treating the environmental impact of energy activities and in this way endogenises pollution abatement. It relies on a quality-of-life penalty function that includes a preference rate depending on pollutant emissions. Another specification endogenises emission taxation by integrating a cost-based penalty function that incorporates a preference rate in the formulation which is related to the level of emission tax and pollutant emissions.

The model is calibrated and solved to discuss the economic impacts of various energy and environmental policy issues in Turkey. Model validity is questioned by comparing initial period forecasts to actual data and by computing the implied income and price elasticities through simulated experiments. A number of non-environmental scenarios investigate consequences of currently relevant energy policy issues in Turkey. Environmental policy scenarios on the other hand simulate European emission standards either by imposition of upper bounds on emissions or by environmental taxation. Results are compared with the outcome of a Business-As-Usual scenario and policy implications are discussed. The interaction of energy decisions with environmental policies is elaborated under a set of interacting scenarios that combine environmental policy scenarios with non-environmental ones.

Non-environmental scenarios that do not target at pollutant emission reductions are comprised of anti-nuclear scenarios and differing energy price scenarios. Results of the anti-nuclear scenarios show that a limit on nuclear energy causes significant economic losses. It is found that a restrictive nuclear policy that limits new plant sizes by 1400 MW per period implies 5% GDP loss in 2035 corresponding to 54 billion dollars and a no-nuclear policy implies 7% GDP loss corresponding to 61 billion dollars. It is also found that anti-nuclear policies increase the dependency on imported fuels as more imports of oil&gas are required to substitute for the implied energy loss. Results under differing energy price assumptions indicate that the model is highly sensitive to energy price variations, especially natural gas and nuclear energy. The findings are such that each 2 cent/kwh rise in expected nuclear power generation cost postpones the nuclear program by 5 years. It is found that the GDP loss induced by a doubling of costs remains below 1% of GDP until 2035. The economic impacts of unexpectedly high nuclear prices are therefore quite limited in comparison to the huge economic losses implied by anti-nuclear policies. In conclusion model results reveal the importance of nuclear energy for economic growth and suggest not to follow anti-nuclear policies in spite of the uncertainties regarding the expected cost of nuclear power generation.

Environmental scenarios that aim to reduce pollutant emissions to levels as foreseen by European standards are comprised of environmental tax scenarios and direct control scenarios that place upper bounds on emissions and so enforce abatement without taxation. Results of the model indicate that economic losses caused by emission restrictions may be quite limited under rational policies. The GDP losses by an adaptation of European emission standards remain in both the direct control and environmental tax scenarios below 1.5% of GDP until 2030. Model results show that a faster shift in the energy system towards less polluting fuels and technologies reduces the economic burden in the long run. This occurs because the economy adjusts itself under tighter emission limits early from initial periods to more stringent standards and a less comprehensive adaptation is required in the long run. In other words, a transitionary phase that initially allows more pollutant emissions necessitates in the long run more sacrifice from economic growth in order to achieve the same emission ceiling. This means that a transitionary agreement allowing less stringent emission standards for Turkey in early EU membership years is in the long run not in the advantage of the country if more stringent standards are to be adopted later on. Turkey should therefore exploit financial support possibilities in international negotiations in order to comply with European emission standards instead of negotiating for more flexible emission standards in early EU membership years.

Model results show that the choice of the economic measure to reduce emissions affects the level of economic loss. It is found that the sulphur tax scenarios' marginal abatement costs are higher than those of SO_2 emission tax scenarios. Accordingly, it is concluded that a tax on SO_2 emissions is more effective in reducing SO_2 emissions than a tax applied on the sulphur content of fuels. It is also found that a constant tax policy is in the long run more effective than a gradually decreasing one as suggested by the tax-endogenised model.

Results from the interaction of various nuclear policies with EU emission restrictions show that nuclear energy restricting policies inflate the costs of reducing pollutant emissions to EU levels. The pollution abatement cost of a no-nuclear policy in terms of GDP loss is found to be approximately twice as much as would be in the case of a standard nuclear policy under BAU assumptions. Thus, if Turkey should reduce its pollutant emissions to comply with European standards, it would have to suffer considerable economic losses from anti-nuclear policies. This economic loss is only compensated when there is a sufficient reduction in the prices of alternative energy sources. Pro-nuclear policies with stronger nuclear engagement on the other hand are found to accelerate economic growth. It is found that even the economic loss implied by EU emission restrictions is limited in the case of an expansion in the nuclear program.

Results from the interaction of various nuclear policies with differing imported fuel price assumptions reveal once again the importance of nuclear power for the Turkish economy. Results show that lower oil and gas prices can reduce the economic burden of anti-nuclear policies whereas higher prices can easily lead to an economic crisis. However, the findings are such that policies with expanded nuclear capacity decrease the economic loss implied by a higher imported energy bill. That is, anti-nuclear policies increase Turkey's dependence on fuel imports so that the Turkish economy becomes more sensitive on imported energy price movements.

In short, it can be said that model results point out that Turkey can reduce its pollutant emissions with little sacrifice from economic growth. However, in order to achieve this, it is necessary to apply rational policies that introduce efficient economic measures for pollution abatement and that make use of appropriate energy technologies. Model results indicate that such strategies using an efficient mix of appropriate energy and economic policies are feasible. Model results also indicate that irrational energy policies can lead to significant economic losses. It is therefore very important that Turkey's national energy plans are developed by elaborating the mutual interactions between energy policies, environmental impacts and economic development as has been done in this research.

It should be noted that the above conclusions are based on the input assumptions and therefore a different set of assumptions may lead to different quantitative results. One caveat is that model projections are based on 1991 balance of payments disregarding possible changes due to new trends. Furthermore, it should be stressed that the presented results are discussed with focus on air pollutant emissions and another caveat is that the environmental cost of nuclear power generation has not be taken into consideration in this study. The findings may change when other environmental aspects like the nuclear waste disposal problem or the risk of a nuclear accident are considered.

Further research is needed towards differentiating various economic agents and integrating the microeconomic foundations implied by those agents' behaviours into the model formulation. One such possibility is the development of a welfare ordering utility function which orders collective outcomes on the basis of individual preferences. In this way it could be possible to distinguish the government as an economic agent and discuss alternative ways of using environmental tax revenues. Further research is also needed towards the integration of externalities into the utility function. Experimentation with alternative forms and comparison of results with the form proposed in this research is required to gain more insight. Further work is also needed towards integrating renewable energy alternatives and towards reducing cost uncertainties related with nuclear power generation. Research should also be directed towards differentiating installed capacity and power generation in the model. The developed model computes electricity generation by plant type as a continuous variable based on the assumed load factors and does not consider installed capacities since the differentiation of capacity causes computational problems as the model becomes a mixed integer one. The indivisibility of power plants is therefore another issue requiring further work. Further work is also needed to extend the environmental submodel so as to consider other environmental aspects such as global warming and water pollution. Finally, further research is required to include externalities related to nuclear power plants that have not been considered in this study; these include the fear of nuclear leakage and the problem of radioactive waste disposal. One possibility is to incorporate a damage function that attempts to value these externalities.

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APPENDIX A

ANALYTICAL DESCRIPTION OF ENVEES

Maximise $U = \sum_t (1/(1-\delta))^t \log (C_t)$

Subject to

$$YN_t=\gamma_t\{\alpha_t[(KDN_t^{skd} KFN_t^{skf})^{sk} LN_t^{sl}]^{\rho}+\beta_t INTN_t^{\rho}+(1-\alpha_t-\beta_t)[EN_t^{s} PN_t^{sp} SN_t^{ss}]^{\rho}\}^{1/\rho}$$

$$Y_t = YN_t + \lambda^p Y_{t-1}$$

$$KD_t = KDN_t + \lambda^p KD_{t-1}$$

$$KF_t = KFN_t + \lambda^p KF_{t-1}$$

$$L_t = LN_t + \lambda^p L_{t-1}$$

$$INT_t = INTN_t + \lambda^p INT_{t-1}$$

$$E_t = EN_t + \lambda^p E_{t-1}$$

$$P_t = PN_t + \lambda^p P_{t-1}$$

$$S_t = SN_t + \lambda^p S_{t-1}$$

$$KDNt = 0.5 p (IDt + IDt-1)$$

$$KFNt = 0.5 p (IFt + IFt-1)$$

$$GDP_t = C_t + ID_t + IF_t + X_t - M_t$$

$$Y_t = GDP_t + INT_t + \overline{EC}_t$$

$$M_t = IF_t + INT_t + EF_t + CG_t$$

$$ID_T = (gd + 1-\lambda) KD_T$$

$$IF_T = (gf + 1-\lambda) KF_T$$

$$M_t \leq X_t + F_t + W_t + TR_t$$

$$F_t \leq \mu_t \, GDP_t$$

$$\varnothing_1 \, GDP_t \leq X_t \leq \varnothing_2 \, GDP_t$$

$$\eta_1 \, GDP_t \leq CG_t \leq \eta_2 \, GDP_t \quad .$$

$$E_t = \sum_j \sum_k ELEC_{j,k,t} \quad \text{(j= hydroel.(6 types), lignite (4 types), hardcoal, nat.gas, petr., nuclear)}$$

$$P_t = \sum_j \sum_k NE_{j,k,t} \quad \text{(j= gas,petroleum)}$$

$$S_t = \sum_j \sum_k NE_{j,k,t} \quad \text{(j=coal,lignite,wood,plant\&animal wastages)}$$

$$CO_{j,k,t} = NE_{j,k,t} + e \; ELEC_{j,k,t}$$

$$CO_{j,k,t} = FCO_{j,t} + DP_{j,k,t}$$

$$NE_{j,k,t} = FNE_{j,t} + DNE_{j,k,t}$$

$$FNE_{j,t} \leq FCO_{j,t}$$

$$DNE_{j,k,t} \leq DP_{j,k,t}$$

$$ELEC_{j,k,t+1} = p \, ELECINC_{j,k,t+1} + ELEC_{j,k,t} - (p/30) \, ELEC0_{j,k} \qquad \text{for } t \leq (30/p)$$

$$ELEC_{j,k,t+1} = p \, ELECINC_{j,k,t+1} + ELEC_{j,k,t} - p \, ELECINC_{j,k,t-(30/p)} \qquad \text{for } t > (30/p)$$

$$NE_{j,k,t+1} = p \, NEINC_{j,k,t+1} + NE_{j,k,t}$$

$$EF_t = \Sigma_j \, FCO_{j,t} \, PIF_{j,t}$$

$$SNE_{j,k,t,l} = sdl \; NE_{j,k,t}$$

$$EPOL_{x,j,k,t} = efe_{x,j,k} \; ELEC_{j,k,t}$$

$$NEPOL_{x,j,k,t,l} = efne_{x,j,k,l} \; SNE_{j,k,t,l}$$

$$POL_{x,j,k,t} = EPOL_{x,j,k,t} + \Sigma_l \, NEPOL_{x,j,k,t,l}$$

$$AIR_{x,j,k,t} = POL_{x,j,k,t} - FILT_{x,j,k,t}$$

$$SO2_t = \Sigma_j \, \Sigma_k \, AIR_{x,j,k,t} \quad \text{for } x=SO_2$$

$$NOX_t = \Sigma_j \, \Sigma_k \, AIR_{x,j,k,t} \; \text{for } x=NO_x$$

$$\Sigma_s \, REDE_{x,j,k,t,s} \leq ELEC_{j,k,t}$$

$$\Sigma_s \, REDNE_{x,j,k,t,l,s} \leq SNE_{j,k,t,l}$$

$$REDE_{x,j,k,t+1,s} = p \;\; REDEINC_{x,j,k,t+1,s} + REDE_{x,j,k,t,s} \qquad \text{for } t \leq 30/p,$$

$$REDE_{x,j,k,t+1,s} = p \, REDEINC_{x,j,k,t+1,s} + REDE_{x,j,k,t,s} - p \, REDEINC_{x,j,k,t-(30/p),s} \quad \text{for } t > 30/p,$$

$$REDNE_{x,j,k,t+1,l,s} = p \;\; REDNEINC_{x,j,k,t+1,l,s} + REDNE_{x,j,k,t,l,s} \qquad \text{for } t \leq 30/p,$$

$$REDNE_{x,j,k,t+1,l,s} = p\ REDNEINC_{x,j,k,t+1,l,s} + REDNE_{x,j,k,t,l,s} - p\ REDNEINC_{x,j,k,t-(30/p),l,s} \quad \text{for } t > 30/p$$

$$EC_t = \Sigma_j \Sigma_k\ ELEC_{j,k,t}\ ecost_{j,k,t} \div \Sigma_j\ FNE_{j,t}\ pif_{j,t} + \Sigma_j \Sigma_k\ DNE_{j,k,t}\ pdf_{j,k,t} + \Sigma_x \Sigma_j \Sigma_k \Sigma_s\ REDE_{x,j,k,t,s}\ redecost_{x,j,k,t,s} + \Sigma_x \Sigma_j \Sigma_k \Sigma_l \Sigma_s\ REDNE_{x,j,k,t,l,s}\ rednecost_{x,j,k,t,l,s}$$

$$EF_t = \Sigma_j\ FCO_{j,t}\ pif_{j,t} + \Sigma_x \Sigma_j \Sigma_k \Sigma_s\ REDE_{x,j,k,t,s}\ redecost_{x,j,k,t,s}\ f_{x,j,k,s} + \Sigma_x \Sigma_j \Sigma_k \Sigma_l \Sigma_s\ REDNE_{x,j,k,t,l,s}\ rednecost_{x,j,k,t,l,s}\ f_{x,j,k,s}$$

$$TAX1_t = NOX_t\ t_{NOx} + SO2_t\ t_{SO2}$$

$$TAX2_t = \Sigma_j FUEL_{j,t}\ s_j\ t_{sulphur}$$

$$\overline{EC_t} = EC_t + TAX1_t + TAX2_t$$

VARIABLES:

$AIR_{x,j,k,t}$	: Total net amount of x type pollutant diffused in the atmosphere by j,k type fuel use
CG_t	: Imports of consumption goods
$CO_{j,k,t}$	: Total consumption of fuel type j group k
C_t	: Consumption
$DNE_{j,k,t}$	: Domestic amount of NEj,k,t
$DP_{j,k,t}$	: Domestic production of jk type fuel
EC_t	: Total energy cost
EF_t	: Cost of fuel imports
$ELECINC_{j,k,t}$	: Annual incremental electricity consumption which is produced by j, k type fuel fired power plant
$ELEC_{j,k,t}$	: Electricity consumption which is produced by the k th group of j type fuel fired power plant
$EPOL_{x,j,k,t}$	: Part of $POL_{x,j,k,t}$ resulting from electricity generation
E_t	: Total electricity consumption
$FCO_{j,t}$	: Consumption of imported j type fuel
$FILT_{x,j,k,t}$	: Amount of x type pollutant from j,k type fuel use filtered by abatement activities
$FNE_{j,k,t}$	: Imported amount of NEj,k,t
F_t	: Capital inflows from abroad
GDP_t	: Gross domestic product
ID_t	: Domestic money component of investments
IF_t	: Investments made with foreign capital goods
INT_t	: Imports of intermediate goods excluding fuels
KD_t	: Domestic capital stock

KF_t : Foreign capital stock
L_t : Labour stock
M_t : Total imports
$NEINC_{j,k,t}$: Annual incremental j k type fuel consumption for nonelectric use
$NE_{j,k,t}$: Consumption of the k th group of j type fuel for nonelectric use
$NEPOL_{x,j,k,t,l}$: Part of $POL_{x,j,k,t}$ resulting from l type nonelectric use
NOX_t : Total NO_X emissions
$POL_{x,j,k,t}$: Amount of x type pollutant produced through use of j,k type fuel
P_t : Oil and gas consumption
$REDE_{x,j,k,t,s}$: Installed abatement activity s in power plants
$REDNE_{x,j,k,t,l,s}$: Installed abatement activity s in industry
S_t : Solid fuel consumption
$SO2_t$: Total SO_2 emissions
$TAX1_t$: Emission tax
$TAX2_t$: Sulphur tax
TR_t : Tourism revenues
W_t : Factor incomes from abroad
X_t : Total exports
Y_t : Gross production
$EN_t, INTN_t, KDN_t, KFN_t, LN_t, PN_t, SN_t$: Incremental $E_t, INT_t, KD_t, KF_t, L_t, P_t, S_t$

INDICES:

j : Index for energy types
k : Index for subenergy types
l : Index for sectors
s : Index for emission control technologies
t : Index for years which represent periods
T : Terminal period
x : Index for pollutant types

PARAMETERS AND CONSTANTS:

λ : Annual survival factor ; $(1-\lambda)$ denotes stock depreciation.
$\mu_t, \phi_1, \phi_2, \eta_1, \eta_2, \gamma_t, \alpha_t, \beta_t$: Scale parameters
δ : Annual cost and utility discount rate
e : Required thermal fuel for unit electric production
$efe_{x,j,k}$: Emission factor of x type pollutant resulting from j,k type fuel use for electricity generation
$efne_{x,j,k,l}$: Emission factor of x type pollutant resulting from l type nonelectric use of j,k type fuel
$eye_{x,s}$: Removal efficiency of control technology s for x type pollutant from power plants

$eyne_{x,l,s}$: Removal efficiency of control technology s for x type pollutant from l type nonelectric use

$f_{x,j,k,s}$: Investment-fraction of total cost of x type pollutant and j,k type fuel related s type abatement technology

gd : Post terminal domestic growth rate

gf : Post terminal foreign growth rate

p : Period length in years

sd_l : Sectoral distribution of nonelectric energy

sk : Value share of capital within capital-labor pair

skd : Value share of domestic capital within domestic and foreign cap.

se : Value share of electricity within energy aggregates

skf : Value share of foreign capital within domestic and foreign cap.

sl : Value share of labor within capital-labor pair

sp : Value share of oil&gas within energy aggregates

ss : Value share of solids within energy aggregates

APPENDIX B

DETAILED BUSINESS-AS-USUAL RESULTS

The model's BAU results are presented in the following in detailed tabular form.

Table B.1. BAU Macroeconomic Results (10^9 US $)

	1995	**2000**	**2005**	**2010**	**2015**	**2020**
GDP	168.483	200.900	249.936	309.690	380.365	469.846
Investments	41.982	59.510	81.363	94.193	116.047	138.948
Foreign Debt	58.904	77.193	99.735	127.716	162.219	204.729
Exports	21.219	30.993	40.924	51.079	62.969	78.238
Imports	35.778	48.623	62.484	77.423	95.091	117.462
Import Compos.						
Fuels	3.150	7.021	7.874	9.525	12.984	18.371
Intermediates	22.204	26.270	34.955	44.961	55.982	68.661
Cons. Goods	2.390	4.612	5.249	6.026	6.945	8.108
Cap. Goods	8.034	10.720	14.406	16.911	19.180	22.322
	2025	**2030**	**2035**	**2040**	**2045**	**2050**
GDP	577.731	710.509	876.125	1087.522	1331.583	1604.415
Investments	164.612	193.838	242.356	298.895	317.035	433.342
Foreign Debt	257.108	321.520	400.852	499.034	619.990	765.289
Exports	96.590	119.267	147.793	184.777	226.752	265.377
Imports	144.433	177.627	219.031	271.880	332.896	393.604
Import Compos.						
Fuels	25.788	38.038	57.610	85.108	121.358	155.462
Intermediates	82.577	97.352	113.041	130.773	148.700	165.474
Cons. Goods	9.511	11.237	13.390	16.138	19.311	22.467
Cap. Goods	26.557	31.000	34.990	39.861	43.527	50.201

Table B.2. BAU Energy Aggregates

	1995	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Electricity (Twh)	86.126	127.508	189.614	280.191	377.224	510.663	673.985	887.696	1172.626	1564.857	2050.975	2490.176
Oil&gas (Mtoe)	35.010	50.923	50.855	53.776	63.517	75.840	91.389	116.802	155.169	201.839	256.064	294.942
Solids (Mtoe)	22.466	32.477	47.039	65.350	82.572	111.721	148.493	181.659	211.777	240.513	285.596	358.466

Table B.3. BAU Primary Energy Consumption (Mtoe)

	1995	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Hardcoal	5.795	11.849	13.238	14.109	15.416	21.261	28.365	38.477	52.866	76.703	113.752	173.447
Natural gas	7.251	15.028	15.028	17.869	27.276	39.315	54.751	80.165	118.532	165.201	219.427	258.305
Oil	27.759	35.895	35.827	35.906	36.241	36.526	36.638	36.638	36.638	36.638	36.638	36.638
Lignite	16.671	20.628	33.801	51.241	67.156	90.460	120.128	143.181	158.911	163.809	171.843	185.019

Table B.4. BAU Electricity Composition (Twh)

	1995	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Hydroelectricity	35.529	48.829	80.332	117.832	132.712	141.659	141.659	141.659	141.659	141.659	141.659	141.659
Lignite	25.355	33.384	64.373	98.704	132.169	180.172	241.305	293.126	330.919	340.919	356.528	380.638
Nuclear	0	0	0	7.000	14.000	25.400	43.900	67.500	106.000	168.000	260.800	414.600
Oil	5.356	8.239	7.474	6.709	5.944	5.179	4.414	3.649	0	0	0	0
Hardcoal	2.327	3.074	3.452	3.004	2.557	13.509	27.562	50.714	88.020	149.194	248.994	409.794
Natural gas	17.560	33.982	33.982	46.941	89.842	144.744	215.146	331.048	506.028	765.085	1042.994	1143.485

Table B.5. BAU Pollutant Emissions (10^6 Tons)

		1995	2000	2005	2010	2015	2020
SO_2	Total	2.000	2.870	4.849	6.214	7.897	10.182
Power plants:							
	Lignite	1.082	1.614	3.555	4.880	6.845	8.652
	Oil	0.018	0.028	0.025	0.023	0.020	0.018
	Hardcoal	0.005	0.007	0.008	0.007	0.006	0.032
	Nat. gas	0.012	0.022	0.022	0.030	0.057	0.092
Nonelectric:							
	Lignite	0.287	0.287	0.287	0.287	0.287	0.287
	Oil	0.427	0.544	0.547	0.553	0.564	0.573
	Hardcoal	0.142	0.309	0.345	0.375	0.418	0.469
	Nat. gas	0.025	0.059	0.059	0.059	0.059	0.059
NO_x	Total	0.668	0.904	1.009	1.130	1.272	1.502
Power plants:							
	Lignite	0.073	0.100	0.194	0.297	0.398	0.542
	Oil	0.013	0.019	0.018	0.016	0.014	0.012
	Hardcoal	0.007	0.010	0.011	0.010	0.008	0.043
	Nat. gas	0.010	0.018	0.018	0.025	0.049	0.078
Nonelectric:							
	Lignite	0.023	0.023	0.023	0.023	0.023	0.023
	Oil	0.496	0.632	0.636	0.643	0.655	0.667
	Hardcoal	0.032	0.069	0.077	0.084	0.093	0.105
	Nat. gas	0.013	0.031	0.031	0.031	0.031	0.031

		2025	2030	2035	2040	2045	2050
SO_2	Total	13.081	16.204	18.653	19.297	20.379	21.689
Power plants:							
	Lignite	11.414	14.361	16.585	16.858	17.518	18.423
	Oil	0.015	0.012	0	0	0	0
	Hardcoal	0.065	0.120	0.208	0.352	0.588	0.967
	Nat. gas	0.137	0.211	0.323	0.517	0.704	0.729
Nonelectric:							
	Lignite	0.287	0.287	0.287	0.287	0.287	0.287
	Oil	0.580	0.585	0.608	0.608	0.608	0.608
	Hardcoal	0.524	0.567	0.583	0.616	0.616	0.616
	Nat. gas	0.059	0.059	0.059	0.059	0.059	0.059
NO_x	Total	1.787	2.093	2.443	2.904	3.484	4.073
Power plants:							
	Lignite	0.726	0.882	0.996	1.091	1.193	1.246
	Oil	0.010	0.009	0	0	0	0
	Hardcoal	0.088	0.162	0.282	0.477	0.797	1.311
	Nat. gas	0.116	0.179	0.273	0.437	0.596	0.617
Nonelectric:							
	Lignite	0.023	0.023	0.023	0.023	0.023	0.023
	Oil	0.674	0.680	0.707	0.707	0.707	0.707
	Hardcoal	0.117	0.127	0.130	0.137	0.137	0.137
	Nat. gas	0.031	0.031	0.031	0.031	0.031	0.031

VITA

Gürkan Kumbaroğlu was born in Trabzon, on March 29, 1969. He received his B.S. degree in Industrial Engineering in June 1990 from Gazi University, Ankara, Turkey.

From 1990 to 1992, he worked for Gebrüder Sulzer AG, in Switzerland, in the plants Zuchwil and Rüti of the group's weaving machines production division. He first practised in various departments under a special engineering trainee program and then worked as a logistics assistant.

He decided to complete his graduate education and registered in 1992 for the M.S. program in the Industrial Engineering department of Middle East Technical University (METU). He received his M.S. degree in Industrial Engineering from METU in January 1995. Since then he has been studying to fulfil the requirements of the Ph.D. program in Industrial Engineering of METU. He is working as a graduate assistant in the Industrial Engineering department of METU since 1993. He has also been working as an editorial assistant of 'Transactions on Operational Research' - a publication of the Turkish Operational Research Society - since 1995. From 1999 to 2000 he has worked for the Turkish Republic State Planning Organisation as a member of the 'Special Committee on Climate Change' in preparing the related parts of the eighth National Development Plan.

His main areas of academic interest include energy modelling, energy-economy-environmental integrated planning and policy analysis. He has several publications in this area and presented various papers at national and international conferences.