MATHEMATICAL MODELING FOR ENERGY POLICY ANALYSIS

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ABSTRACT

MATHEMATICAL MODELING FOR ENERGY POLICY ANALYSIS

Kat, Bora

Ph.D., Industrial Engineering Department

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As is now generally accepted, climate change and environmental degradation has largely been triggered by carbon emissions and energy modeling for policy analysis has therefore attained renewed urgency. It is important for governments to satisfy emission targets and timetables set down by international agreements without disregarding macroeconomic concerns and restrictions. In this study, we present a large-scale nonlinear optimization model that allows the analysis of macroeconomic and multi-sectoral energy policies in respect of technological and environmental options and scenarios. The model consists of a detailed representation of energy activities and disaggregates the rest of the economy into five main sectors. Economy-wide solutions are obtained by computing a utility maximizing aggregate consumption bundle on the part of a representative household. Intersectoral and foreign transaction balances are maintained using a modified accounting matrix. The model also computes the impact on macroeconomic variables of greenhouse gas (GHG) emission strategies and abatement schemes. As such the model is capable of producing solutions that can be used to benchmark regulatory instruments and policies. Several scenarios are presented for the case of Turkey in which the impact of a nuclear power programme and power generation coupled with carbon-capture-and-storage schemes are investigated as well as setting quotas on total and sectoral

GHG emissions.

Keywords: Energy-economy-environment modeling, optimization, nuclear power, policy analysis, CO_2 capture and storage technology, GHG emissions

ÖZ

ENERJİ POLİTİKALARI ANALİZİ İÇİN MATEMATİKSEL MODELLEME

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İklim değişikliği ve çevre kirliliğinin ağırlıklı olarak karbon salınımı kaynaklı olduğu artık genel kabul görmüş olup, politika analizine yönelik enerji modelleme çalışmaları yeniden önem kazanmıştır. Bununla birlikte, uluslararası antlaşmalar ile belirlenen hedeflerin ve programların makroekonomik kaygıları ve kısıtlamaları da gözeterek yerine getirilmesi hükümetler için önemlidir. Bu çalışmada, makroekonomik ve çok sektörlü enerji politikalarını teknolojik ve çevresel alternatifler ve senaryolar açısından analiz etmeye yönelik büyük ölçekli ve doğrusal olmayan bir optimizasyon modeli sunulmuştur. Önerilen modelde, enerji ile ilgili aktiviteler detaylı bir şekilde temsil edilmiş, diğer ekonomik faaliyetler ise beş ana sektörde ele alınmıştır. Ekonominin bütününü kapsayan çözümler, temsili bir tüketicinin faydasını maksimize eden toplam tüketim demeti üzerinden elde edilmiştir. Sektörler arası ve uluslararası işlem dengeleri, sosyal hesaplar matrisinin modelin yapısına göre uyarlanması ile sağlanmıştır. Sera gazı salınımlarının azaltılmasına yönelik stratejilerin ve teknolojilerin makroekonomik etkileri de önerilen model ile hesaplanabilmektedir. Model, bu anlamda, düzenleyici uygulamalar ve politikalar için emsal alınabilecek sonuçlar üretmeye vakıftır. Çalışma kapsamında, nükleer elektrik santrallerinin kurulmasına yönelik bir programı ve karbon tutma ve depolama teknolojisine sahip elektrik santrallerini ele alan senaryoların yanısıra, ülke genelinde veya

sektörel bazda sera gazı salınımları üzerine kota konulmasını ele alan senaryolar tanımlanmış ve bu senaryoların etkileri araştırılmıştır.

Anahtar Kelimeler: Enerji-ekonomi-çevre modellemesi, optimizasyon, nükleer elektrik, politika analizi, CO_2 tutma ve depolama teknolojisi, sera gazları salınımı

to the beloved memory of HALUK OSMAN OKTAR

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LIST OF ABBREVIATIONS

CH_4	Methane
CO_2	Carbon Dioxide
N_2O	Nitrous Oxide
C-D	Cobb-Douglas
CCS	Carbon Capture and Storage
CES	Constant Elasticity of Substitution
CGE	Computable General Equilibrium
DSİ	General Directorate of State Hydraulic Works
EÜAŞ	Electricity Generation Company Incorporated
EİE	General Directorate of Electrical Power Resources Survey and Development Administration
EPDK	Energy Market Regulatory Authority
ETA	Energy Technology Assessment
EU	European Union
GAMS	General Algebraic Modeling System
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GJ	Giga-joule
GNP	Gross National Product
GW	Gigawatt

GWh	Gigawatt-hours
IEA	International Energy Agency
IPCC	The Intergovernmental Panel on Climate Change
kcal	kilocalorie
ktoe	Kilotonne of oil equivalent
kton	kilotonne
kW	kilowatt
kWh	kilowatt-hours
LNG	Liquified Natural Gas
LUCF	Land use Change and Forestry
MBtu	Million British Thermal Units
MENR	Ministry of Energy and Natural Resources
MTA	General Directorate of Mineral Research and Exploration
Mtoe	Million tonnes of oil equivalent
MW	Megawatt
MWh	Megawatt-hours
NIR	National Inventory Report
OPEC	Organization of the Petroleum Exporting Countries
SAM	Social Accounting Matrix
TÜİK	Turkish Statistical Institute
TEK	Turkish Electricity Authority
TKİ	Turkish Coal Enterprises
TL	Turkish Lira
TTK	Turkish Hardcoal Enterprise
TW	Terawatt

TWh	Terawatt-hours
UNEP	United Nations Environment Programme
WEO	World Energy Outlook
WMO	World Meteorological Organization

CHAPTER 1

INTRODUCTION

Energy plays a crucial role in economic and social development of human societies. Since the industrial revolution, the demand for energy has increased significantly since it is essential in industrial, service and agricultural activities as well as for residential use. This crucial need for and the increased use of energy brings with it a number of problems that can be discussed under two main categories: problems arising from the uneven distribution of energy resources among countries and the environmental effects of increasing consumption. Uneven distribution of energy resources among countries provides political and strategic advantages to countries or organizations that control energy resources. These countries can use their power by manipulating the prices or they may even suspend or terminate supplies. Besides these threats, competition among countries and international corporations over energy sources, attacks on energy infrastructure, accidents and natural disasters also affect the distribution and use of energy. Such uncertainties and threats force governments to search for ways to decrease the level of dependency on energy imports and increase the variety of supply sources in order to enhance supply security. Similarly, efforts for developing energy efficient technologies has been hastened in the last decades.

There is a close relationship between the environment and production and consumption activities. The effects of pollutant emissions on ecological balances have climbed to significant levels in the twentieth century. There now exists considerable research evidence that brings out the deterioration inflicted on the environment. A most telling finding from these studies is that there has been a 0.75 degrees Celsius increase in the global surface temperature in the recent century [1]. More dramatically, it is expected that global surface temperature will rise a further 1.1 degrees Celsius to 6.4 degrees Celsius during the twenty-first century, [1]. The Intergovernmental Panel on Climate Change (IPCC), established in 1988 by two United Nations organizations, the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP), declared in their fourth assessment report that global warming was man-made with more than 90% probability, which is their strongest conclusion to date. Nonetheless, IPCC has the opinion that the global warming can be slowed down but only if governments act decisively.

In the light of facts summarized above, the energy policy of a country can be stated as providing a minimum cost continuous and sustainable energy supply satisfying the environmental targets proposed by various international agreements such as Kyoto Protocol; which Turkey finally signed in February 2010.

The literature on national and international energy modeling dates well back but has proliferated in nineteen-seventies, following the sharp increase in energy costs following the Yom Kippur War and the resulting Arab Oil Embargo in 1973 and also the start of Iran-Iraq War in 1979. The studies reported before this period were mainly of the type of demand analysis and forecasting. Gross national product (GNP) growth rate was considered as the primary determinant of energy demand in these studies and models describing energy demand exogenously were solved to minimize the costs of energy supply. This treatment worked well in the 1950-70 period when there was a smooth, continuous progress in energy costs.

It was realized in the seventies that energy policy would have to be studied in an economy-wide framework in order to represent the interaction between the energy sector and the rest of the economy. The first attempts produced partial equilibrium models describing GNP growth rate as an exogenous variable and representing a one-way linkage between energy and the rest of the economy. Among several such tecno-economic models the Energy Technology Assessment (ETA) model, [2], developed by Alan Manne is a partial equilibrium model employed primarily in the nuclear power debate in the U.S.. In ETA, GNP growth is determined by the labor force and per capita productivity considerations, hence the effects of rising energy costs and limited supplies on the growth rate of the GNP could not be represented, as was the case with other partial equilibrium models. General equilibrium models, on the other hand, allow for a two-way linkage between energy and the rest of the economy, i.e., substitution and complementarity relations exist not only among energy alternatives, but also between the energy alternatives and the other inputs. A prominent example for such models is Manne's

ETA-Macro [3]. Güven [4] reformulated Manne's model to include foreign trade and currency restrictions. The inclusion of foreign trade enhances the representativeness of the model for countries in which growth is highly dependent on foreign capital inflows. These are optimization models and an "equilibrium" is computed by maximizing consumers' overall utility from consumption while energy costs are "minimized" with this provision.

With advances in computing capability and software, the use of so called computable general equilibrium (CGE) models has become widespread in economics. These models are better in analyzing market economies compared to traditional input-output and linear or nonlinear programming models which are more suitable to model economies in which a central authority controls most of the resources and has to make optimal decisions subject to technological and physical constraints. Unlike optimization models, CGE models fully represent the agents and their optimizing behaviors in an economy and compute equilibrium solutions for profit maximizing producers and utility maximizing consumers. It is however not very easy to represent detailed policy options in respect of energy alternatives in CGE models. Such models in other words, have to view technological alternatives in aggregate rather than in detail and from a greater distance. Activity analysis based on optimization models, on the other hand, provides for great flexibility and explicit representation of the energy sector, even though they are not as strong in capturing agent behavior.

Since the Rio Summit on climate change in 1992, models have also had to take into account environmental effects of economic activity. This need has attained urgency with the realization that energy externalities are a contributing factor to climate change. Energy modelers have proposed improvements in their formulations with this view, but in practice it is not yet clear whether socially efficient resource allocation will be achieved by market mechanisms or by quotas and standards, or by going back to centralized management. Current attention tends to focus on market mechanisms, but whether it be taxation or licensing and carbon trading, such mechanisms all have different promises as well as different handicaps. This means in any case that benchmark allocations are needed for ex-ante calculation of tax rates, licensing fees or quotas in view of technological details and policy alternatives.

In this thesis, we develop a multi-sectoral energy-economy-environment model that can be used to generate benchmark solutions for any scenario in respect of energy alternatives. The model is a significant multi-sectoral extension of Güven [4]. The viewpoint taken is that of a social planner seeking efficient solution points computed in terms of a composite welfare function of sectoral goods consumed by a representative household. We formulate the model as a composite of nonlinear activity analysis and a macroeconomic module that allows substitution between primary factors and energy alternatives. This format provides for the assessment of detailed courses of action aiming for carbon abatement or mitigation in respect of the welfare consequences of these alternatives. The model is implemented with the specifics of Turkey in mind, in terms of both disposable resources and policies. We pay particular attention to foreign trade, the exchange rate and the balance of payments since the bulk of energy consumed in Turkey must be imported. This makes the model useful for many economies with similar constraints. The model can be solved on a personal computer running proprietary solvers.

As far as we know, this multi-sectoral model is a first attempt in energy-economy-environment modeling that integrates activity analysis with a disaggregated representation of the economy in optimization framework. It includes five producing sectors: *Agriculture*, *Energy-intensive Industry*, *Other Industry*, *Services* and *Transportation*. The disaggregation seeks to bring out the energy and growth dynamics of the economy taking into account intersectoral transactions and foreign trade. An important issue proposed within the context of this thesis is to integrate the environmental concerns by incorporating an environment module that calculates GHG emissions that result from energy activities.

The thesis is organized in six chapters. Appendices incorporate all numerical results and other technical detail.

A literature survey is presented in Chapter 2 including modeling approaches, classification of energy models, recent trends in energy modeling and a review of the most closely related studies. Chapter 3 summarizes the general energy outlook of Turkey, providing detailed information on energy reserves, primary energy production and total energy supply as well as the general energy balance of the country. The mathematical model is introduced in Chapter 4. Chapter 5 is devoted to results and analysis where we first report findings that leave out any consideration of environmental policies (a base-case, an open and a no-nuclear scenario). We then report findings obtained for scenarios that include environmental policy options such as setting quotas on total GHG emissions as well as on sectoral emissions. We also investigate the feasibility of implementing Carbon Capture and Storage (CCS) technologies and impacts of changes in world energy prices.

The final chapter concludes the report and points out outstanding issues that require further research.

CHAPTER 2

LITERATURE SURVEY

As stated in Chapter 1, the studies on energy modeling were triggered by the sharp increases in energy prices in 1970s. The oil crises (1973 and 1979) experienced in this era exposed the inevitability of modeling energy activities without considering the close links between these activities and the rest of the economy. Besides this, with the immense rise of pollutant emissions in recent decades and concomitant global warming, energy policy modeling has become highly important due to the need for policy analysis in order to satisfy the targets proposed by various international agreements. As a result, analysis of energy systems require both economic and environmental considerations.

With the advance of computer capabilities, a considerable number of energy models have been introduced. In this chapter, before discussing the energy models in the literature, two of the general modeling approaches, optimization and CGE, will be given in an abstract manner. Note that the multi-sector model proposed in this thesis is formulated in the optimization framework, however, one of the main challenges in extending conventional one-sector optimization models into a multi-sector environment was overcome by modifying the Social Accounting Matrix (SAM) which is employed as the database for calibrating the CGE models. After defining the main modeling approaches, general features of these energy models, mainly based on the classification by Beeck [5], will be given first, where the focus will be on the most widely used distinction: bottom-up and top-down approaches. Next, a broad information about the principal models will be given via the comparison and classification studies. Then, recent modeling trends which try to combine bottom-up and top-down approaches in a single framework will be summarized. Finally, the contribution of our study to the literature will be articulated by reviewing the most related studies.

2.1 MODELING APPROACHES

2.1.1 OPTIMIZATION MODELS

Energy models, in the optimization framework, are generally classified into two types based on their objective function. The models of the first type minimize energy cost subject to energy related activities. The models of the second type, on the other hand, maximize welfare of consumers which is generally denoted by a utility function, U, of consumption, C. The model illustrated below is an abstract representation of the conventional one-sector optimization models of the second type. Note that the models employing this modeling approach will be referred to frequently in the rest of the study since the multi-sector model, proposed in this thesis, takes its roots from these models.

$$
\begin{aligned}
& Maximize\ U(C) \\
& s.t. \\
& Y = \Gamma(K, L, E) \\
& E = [t][z] \\
& EC = [p][z] \\
& GDP = C + INV + X - M \\
& Y = GDP + INT + EC
\end{aligned}
$$

where Y, GDP, E, K, L, INV, INT, X, M and EC denote the gross output, gross domestic product, aggregate of energy inputs, capital, labor, investments, intermediate goods, exports, imports and energy cost; and $[t]$, $[p]$, $[z]$ stand for technology, energy cost parameters and energy activities, respectively. The production function, which combines the capital, labor and energy inputs, is represented by Γ. A realistic model also includes further macroeconomic equations, and bounds on some of the energy activities and macroeconomic variables, which will be discussed more into detail in the following chapters of the study.

2.1.2 CGE MODELS

"CGE models are nonlinear equilibrium models with the ability of dealing with multi-sector economies. They are, in fact, the simulations that combine the abstract general equilibrium structure with realistic data to solve numerically for levels of supply, demand and price that support equilibrium across a specified set of markets", [6]. Unlike the optimization models illustrated above, CGE models fully represent the agents and their optimizing behaviors in an economy, i.e., these models include the equilibrium conditions for profit maximizing producers and utility maximizing consumers. In this section, the algebra of CGE models as well as a brief information about SAMs, the database of CGE models, will be summarized briefly.

Let $i = 1, ..., N$, $j = 1, ..., N$, $d = 1, ..., D$ and $f = 1, ..., F$ denote the commodities, sectors, consumers and factors of production, respectively. CGE models employ the three conditions of general equilibrium which are market clearance, zero profit and income balance. Equation 2.1, market clearance for commodities, assures that the total production of commodity i, y_i, is equal to the sum of commodity i demanded as intermediate good, x_{ij}, from all sectors and as final demand, c_{id}, by all consumers. Equation 2.2, market clearance for factors of production, e.g., capital and labor, assures that supply of factor f equals to the sum of factor f used in sector j, v_{fj}, over all sectors. Zero profit condition is shown in Equation 2.3 which implies that the total value of output in sector j, $p_j y_j$, is equal to the sum of expenditures on intermediates and factor uses where p_j and w_f denote the price of commodity j and factor f, respectively. Finally, Equation 2.4 assures that total income of the consumers is equal to the total factor incomes which is also equal to the total expenditures of the consumers on final consumption.

$$y_i = \sum_{j=1}^{N} x_{ij} + \sum_{d=1}^{D} c_{id} \qquad \forall i \qquad (2.1)$$

$$V_f = \sum_{j=1}^{N} v_{fj} \qquad \forall f \qquad (2.2)$$

$$p_j y_j = p_i \sum_{i=1}^{N} x_{ij} + w_f \sum_{f=1}^{F} v_{fj} \qquad \forall j \qquad (2.3)$$

$$M = \sum_{f=1}^{F} w_f V_f = \sum_{i=1}^{N} \sum_{d=1}^{D} p_i c_{id} \qquad (2.4)$$

Utility maximization problem of consumer d is to decide on the consumption bundle that maximizes her utility subject to the income (m_d) (which she earns by selling her primary factor endowments in the market) constraint.

$$
\begin{aligned}
&Maximize_{c_{id}}\ U(c_{1d}, ..., c_{Nd}) \\
&s.t. \\
&m_d = \sum_{i=1}^{N} p_i c_{id}
\end{aligned}
$$

Profit maximization problem of producer j is:

$$
\begin{aligned}
&Maximize_{x_{ij}, v_{fj}}\ p_j y_j - \sum_{i=1}^{N} p_i x_{ij} - \sum_{f=1}^{F} w_f v_{fj} \\
&s.t. \\
&y_j = \Gamma(x_{1j}, ..., x_{Nj}, v_{1j}, ..., v_{Fj})
\end{aligned}
$$

where U and Γ represent the utility and production functions, respectively. Note that the expression in the objective function, revenue of the producer minus her payments for intermediate goods and factors of production, denotes the producer's profit. The producer then aims to maximize the profit subject to her technological constraints, i.e., the output of the producer is determined via a production function of primary factor endowments and intermediate goods.

Solving Equations 2.1-2.4 using the optimality conditions of consumers' and producers' problems for the price and output vectors and income give the equilibrium solution. Note that there are $2N + F + 1$ unknowns ($[y_1, ..., y_N]$, $[p_1, ..., p_N]$, $[w_1, ..., w_F]$ and M) and $2N + F + 1$ equations. Then, the solution gives relative prices; that is why one of the prices is fixed, so-called numeraire, in equilibrium models.

CGE models are calibrated, i.e., parameters for utility and production functions are estimated, on a Social Accounting Matrix (SAM), which is a matrix representation of national accounting balances. A schematic representation of SAM can be seen in Table 2.1 where $\bar{X}$, $\bar{C}$ and $\bar{V}$ represent the intersectoral flows, final demand and value-added activities, respectively. A row sum, in the upper half of the SAM, represents the total revenue received from the sales of a product. This is equal to the sum of the corresponding column in the left half of the SAM, which denotes the total cost of inputs for the product. Note that this equality implies the zero-profit condition in Equation 2.3. Similarly, a row sum in $\bar{V}$ quadrant indicates Equation 2.2. Finally, the sum of the entries in $\bar{V}$ quadrant is equal to the sum of the entries in $\bar{C}$ quadrant, as expressed in Equation 2.4, that is, total factor incomes are equal to the total consumption expenditures.

Table 2.1: Schematic Representation of a Social Accounting Matrix, [6].

		$\leftarrow$	j	$\rightarrow$	$\leftarrow$	d	$\rightarrow$	
		1	...	N	1	...	D	Total
$\uparrow$	1							$\bar{y}_1$
i	$\vdots$		$\bar{X}$			$\bar{C}$		$\vdots$
$\downarrow$	N							$\bar{y}_N$
$\uparrow$	1							$\bar{V}_1$
f	$\vdots$		$\bar{V}$					$\vdots$
$\downarrow$	F							$\bar{V}_F$
Total		$\bar{y}_1$	...	$\bar{y}_N$	$\bar{C}_1$	...	$\bar{C}_D$	

2.2 ENERGY MODELS AND THEIR CLASSIFICATION

Energy models can be classified in various ways since they are very diverse in their characteristics. A comprehensive study on classification of energy models is conducted by Beeck [7], in which she gives nine ways of classifying energy models. Beeck then revised her classification scheme in [5] as listed below (including main modeling approaches for each way of classification).

- Perspective on the Future

  Forecasting, Exploring, Backcasting (looking back from the future)

- Specific Purpose

  Energy demand, energy supply, impacts, appraisal, integrated approach, modular build-up

- The Model Structure: Internal Assumptions and External Assumptions

  Degree of endogenization, Description of non-energy sectors, Description of energy end-uses, Description of supply technologies.

- The Analytical Approach

  Top-Down, Bottom-Up

- The Underlying Methodology

  Econometric, Macro-Economic, Economic Equilibrium, Optimization, Simulation, Spreadsheet/Toolbox, Backcasting, Multi-Criteria

- The Mathematical Approach

  Linear programming, Mixed-integer programming, Dynamic programming

- Geographical Coverage

  Global, Regional, National, Local, Project

- Sectoral Coverage

  Energy sectors, Overall economy

- The Time Horizon

  Short-term, Medium-term, Long-term

- Data Requirements

  Qualitative, Quantitative, Monetary, Aggregated, Disaggregated

As stated at the outset, we will focus on the top-down and bottom-up models in reviewing the literature. In energy-economy modeling, these terms were first used by Grubb et al. [8]. Bottom-up models reflect an engineering view which has a detailed treatment of the energy-producing technologies and try to find the least-cost way of meeting the energy demands subject to the technological restrictions and energy input constraints. These models explore the impacts of changes in fuel use, energy efficiency and emission control technologies, on the energy consumption and environment. Bottom-up models generally lack the interactions with the rest of the economy. Sathaye and Sanstad [9] discuss the bottom-up energy modeling where they classify these models under the following four main categories:

- Energy accounting models
- Engineering optimization models

- Iterative equilibrium models
- Hybrid models

Energy accounting models are simple models which rely on input-output relations. Energy supplies are determined from the energy demand projections using the energy intensities of the activities. There is no feedback between energy sector and the rest of the economy. These models are employed to analyze various scenarios which comprise different projections for energy costs, activities and intensities.

Engineering optimization models utilize linear programming in order to obtain least-cost energy services under the supply, demand and resource constraints. Macroeconomic factors can be integrated into these models via demand projections or as constraints, i.e., constraints on foreign exchange or capital resources.

Iterative equilibrium models aim to reach an equilibrium by iteratively adjusting the prices and quantities in the energy sector. Similar to the optimization models, macroeconomic variables are exogenous, i.e., energy demand is forecasted based on exogenous macroeconomic indicators, and there is not a two-way linkage between energy and the rest of the economy.

The last category in [9] is hybrid models which allow a two-way linkage between energy activities and the rest of the economy, i.e., they provide relations between energy and the other factors of production (capital and labor) using an aggregate production function. The objective of these models is maximizing the discounted utility of the consumers which is generally represented with their consumption amounts. Energy demand and some macroeconomic variables such as GDP growth rate and investment amounts are endogenous variables contrary to the practice in the accounting, optimization or iterative equilibrium models. Hybrid models, on the other hand, represent less detail in the energy end-use technologies compared to the engineering optimization models.

Top-down models, on the other hand, treat the systems using aggregate macroeconomic variables. These models are criticized for not providing energy sector details, and current and future technological options. These models are macro-econometric or CGE models. Key parameters in these models are estimated by econometric tools using the historical data or by calibration, i.e., estimation of parameters using the data for the selected base year.

Table 2.2 lists the main features of the top-down and bottom-up models, [7]. The reader is referred to the study by Lanza and Bosello, [10], for a more comprehensive comparison of top-down and bottom-up modeling approaches.

Table 2.2: Main Features of Top-Down and Bottom-Up Modeling Approaches, Beeck [7]

Top-Down Models	Bottom-Up Models
Use an ”economic approach”	Use an ”engineering approach”
Give pessimistic estimates on ”best” performance	Give optimistic estimates on ”best” performance
Can not explicitly represent technologies	Allow for detailed description of technologies
Reflect available technologies adopted by the market	Reflect technical potential
The ”most efficient” technologies are given by the production frontier (which is set by market behavior)	Efficient technologies can lie beyond the economic production frontier suggested by market behavior
Use aggregated data for predicting purposes	Use disaggregated data for exploring purposes
Are based on observed market behavior	Are independent of observed market behavior
Disregard the technically most efficient technologies available, thus underestimate potential for efficiency improvements	Disregard market thresholds (hidden costs and other constraints), thus overestimate the potential for efficiency improvements
Determine energy demand through aggregate economic indices (GNP, price elasticities), but vary in addressing energy supply	Represent supply technologies in detail using disaggregated data, but vary in addressing energy consumption
Endogenize behavioral relationships	Assess costs of technological options directly
Assumes there are no discontinuities in historical trends	Assumes interactions between energy sector and other sectors are negligible

Based on the classification scheme she proposes in [5], Beeck gives an overview on ten of the existing models: EFOM-ENV, ENERPLAN, ENPEP, LEAP, MARKAL, MARKAL-Macro, MESAP, MESSAGE-III, MICRO-MELODIE and RETscreen.

Among the models classified in [7], EFOM-ENV, MARKAL, MESSAGE-III and RETscreen use bottom-up approaches where ENERPLAN uses a top-down approach. In the models, ENPEP, MARKAL-Macro and MESAP, a hybrid approach is followed, that is, demand analysis is modeled using a top-down approach whereas the supply side has a bottom-up structure. MICRO-Melodie, on the other hand, is a top-down model with a detailed description of the energy sector.

Kumbaroğlu [11] classified 19 of energy-economy and energy-economy-environment models, in addition to EFOM-ENV and MARKAL, based on their market representation (aggregate economic equilibrium, disaggregate economic equilibrium, energy sector equilibrium and energy sector optimization) similar to the classification presented by Beaver [12], time-horizon (short-term, medium-term and long-term) and geographical coverage (national, regional).

Among the 21 models Kumbaroğlu [11] discussed, seven of the models, MOBI-DK, GOULDER, PESTES, JW, MULTI, WARM and DREAM are CGE models which can be classified as top-down models. CETA, MERGE, GLOBAL2100, MIS, RICE and IIAM are the ones employing aggregate general equilibrium approach in which there is a detailed energy sector whereas the rest of the economy is represented in an aggregated fashion, i.e., GDP is determined by an aggregate production function. GEMINI, ERB, ICF and WATEMS-GDL are energy sector equilibrium models which represent only the energy-related sectors. These models rely on microeconomic theory and ignore the interactions between the energy related sectors and the rest of the economy. The last four models considered in [11] are MARKAL, MRMM, EFOM-ENV and PERSEUS-GWI which are classified as energy sector optimization models. The models of this type use linear programming which minimizes total discounted energy costs in an exhaustive energy network. Similar to the energy sector equilibrium models, these models consider only the energy sector and interactions with the remaining sectors are not taken into account.

Huntington and Weyant [13] focused on 16 modeling systems. The models discussed in [13] are ABARE-GTEM, AIM, CETA, FUND, G-Cubed, GRAPE, IGEM, MARKAL-Macro, MERGE 3.0, MIT-EPPA, MS-MRT, NEMS, Oxford Econometrics Model, RICE, SGM, and WorldScan. The models chosen in [13] are supposed to be the most important ones in evaluating climate change policies. They classify these models under five categories based on four attributes, i.e., economy model, fuel supplies and demand by sector, energy technology detail and carbon coefficients.

Two of these models in [13], FUND and RICE, assume carbon as an input to the economy, and use an aggregate production function which generates GDP using capital and labor together with the carbon inputs. Energy sector is represented in an aggregated manner in these models and inter-industry interactions are not taken into consideration.

Second category of the models in [13], including CETA, MARKAL-Macro, MERGE 3.0, NEMS and GRAPE, represent a detailed energy sector where the rest of the economy is aggregated. Again there is an aggregated production function determining GDP using capital, labor and energy as inputs. These models, similar to those in the first category, lack of interindustry interactions.

MIT-EPPA and WorldScan, the models in the third category of [13], are multi-sector general equilibrium models which have the capability of representing interindustry interactions to an extent. In addition to the multi-sector structure, IGEM and G-Cubed comprise macroeconometric features. Oxford Econometrics model, on the other hand, is the only model with a pure macroeconometric structure. Another important feature in which Oxford Econometrics model differs from all the other models is that the model takes unemployment and monetary policy into account. Finally, Abare-GTEM, AIM, MS-MRT and SGM are hybrid models which try to integrate a multi-sector, multi-region economy with a detailed energy sector.

Wei et al. [14] classify and analyze several models developed by international institutions. A brief information about the applications of these models is also given in their study. Besides the classification schemes of content, approach, scope, modeling approach, focus, time scale and model functions; the models discussed in this study are also classified according to their modeling approaches, i.e., top-down, bottom-up and hybrid models. Among these models, CGE, 3Es-Model, Macro and GEM-E3 are classified as top-down models; MARKAL, MESSAGE, EFOM, MEDEE, ERIS, LEAP and AIM are classified as bottom-up models; and NEMS, IIASA-WEC E3, PRIMES, POLES and MIDAS are classified as hybrid modeling approaches.

Capros [15] reviews the approaches in energy, economy and environment modeling and informs the reader of the two EU models, GEM-E3 and PRIMES, both of which are CGE models. GEM-E3 is an 11-country model which covers the entire economy. PRIMES, on the other hand, focuses on energy sector in 12 EU countries.

Burniaux and Truong review several general equilibrium approaches incorporating energy substitution, in their technical report on GTAP-E, [16]. The models reviewed in [16] are CETM, MEGABARE and GREEN. GTAP-E is the extension of the GTAP model (a global CGE model) into which the energy substitution features are incorporated. Considering the advantages and disadvantages of the models under discussion, a top-down approach was chosen in GTAP-E model.

CETM is a partial integration of ETA, a bottom-up energy sector model, and MACRO, a top-down nine-region global CGE model. An equilibrium solution is obtained by iteratively running ETA and MACRO until energy price and quantity variables are equalized in both models. The link between the models is the so called 'soft link' which refers to the combination of two or more models without a full integration in a single model.

MEGABARE model proposes an innovative approach 'technology bundle', which utilizes a weighted combination of different technologies, in order to reflect the technology-rich feature of the bottom-up modeling approach to a top-down model. Only the the electricity and iron and steel sectors are represented with 'technology bundle' in MEGABARE. The resulting model is a CGE model which is developed on the GTAP framework. Another novel feature of MEGABARE is the endogenously determined labor growth.

GREEN is a 12-region dynamic global CGE model focusing on the linkage between energy and economy. A distinctive feature of GREEN is its treatment to energy-capital substitution. Contrary to the most of the models in the literature GREEN assumes a complementarity relation between capital and energy in the short-run.

A comprehensive study on energy models is the ACROPOLIS project conducted by cooperation of 12 organizations, 7 of which are EU organizations, [18]. ACROPOLIS project, with three main objectives ("bridging the gap between modelers and policy makers, addressing policy questions relevant to main stake holders and assessing the impacts of various policies on reducing GHG emissions, and diffusion of cleaner energy technologies", [18]), compares 15 energy models on the basis of four case studies, i.e., internationally tradable green certificates, emissions trading, energy efficiency standards and internationalization of environmental externalities.

Five of the energy models considered within ACROPOLIS project are from the MARKAL modeling family (bottom-up, originally and mostly linear programming models with a high level of detail in representing the energy system), i.e., MARKAL-MATTER (Western Europe), MARKAL-Nordic (Nordic Region), MARKAL-MACRO-IT (Italy), MARKAL-Canada (Canada) and GMM (global). In addition to the MARKAL models, the CGE models, AIM (global), GEM-E3 (global) and NEWAGE (global); the simulation models, POLES (global), NEMS (USA) and NEO-MS (Netherlands), and the linear programming-based models, MESSAGE (global) and TIMES (Germany), are discussed within the project. The last two models taken into consideration within ACROPOLIS are DNE21 (global), an integrated assessment model, and PRIMES (EU countries), a market equilibrium model. Note that, as indicated in the parenthesis following the model names, these models are also grouped based on their geographical coverage, i.e., global, regional or national.

As a result, the ACROPOLIS project has produced insights in several climate policy options by synthesizing the results of different modeling approaches. Furthermore, the project could be considered as a first step in focusing on fewer specialized models for the future studies, i.e., only the relevant models would be further developed for analyzing specific policy options.

Ercan [19] summarizes and discusses 11 of the models which were taken into consideration in the ACROPOLIS project. Moreover, Ercan discusses the current modeling tools used by the Ministry of Energy and Natural Resources (MENR), i.e., MAED module for energy demand forecasting, WASP for the electricity capacity planning and ENPEP for the policy analysis. Ercan criticizes the modeling tools used by MENR for being old-generation and not comprising a macroeconomic module. He also points out that the most important exogenous variable employed in these models, growth rate of the economy, is quite optimistic since it is based on plans and targets proposed by the State Planning Organization. As a result of his discussions, Ercan concludes that employing two types of models, i.e., a dynamic global model, such as POLES or DNE21, to develop a foresight for the global energy market and a national model such as PRIMES to be in line with EU countries, would be preferable for Turkey.

A more serious criticism on ENPEP and MAED is presented by Kumbaroğlu [20], in which high error rates of MADE projections especially in electricity demand are emphasized. Kumbaroğlu addresses the lack of a two-way linkage between energy and economic activities, i.e., there are not sufficient links from energy to economy, which results in a one-way interaction between the modules of ENPEP, as the main drawback of ENPEP model as well as its MAED module. Furthermore, in parallel with the remarks highlighted by Ercan [19], Kumbaroğlu criticizes the use of optimistic values for exogenous inputs, i.e., economic and technological progress, which also affects the reliability of the model projections.

The reader is referred to the survey paper Nakata [21] and Bosello et al. [22] for a more comprehensive classification of the energy models. In [22], Bosello et al. classify more than 40 models in terms of their modeling approach, i.e., top-down (input/output, macroeconometric, general equilibrium, integrated assessment), bottom-up (linear programming and nonlinear programming models), and in terms of their geographical scope, i.e., national, European Union (EU), global and global-regionalised. Nakata classifies a wide range of energy models and discusses the carbon and energy taxation, and the role of nuclear power in the survey paper [21].

2.3 RECENT TRENDS IN ENERGY MODELING

Both bottom-up and top-down models have been esteemed by a wide range of scientists and a great number of models in each modeling approach have been introduced to the literature. The debate around the appropriate modeling approach, however, has been continuing since 1980s. Bottom-up models are criticized for their scant representation of microeconomic realism and macroeconomic completeness. Top-down models, on the other hand, are criticized for being rigid in terms of technological structure, i.e., these models lack technological explicitness and are poor in representing new practices. Hybrid models which combine the two perspectives, emerged as a result of this debate. Figure 2.1 shows the placement of the bottom-up, top-down and hybrid models on a three dimensional representation, [23]. Recent studies achieving a certain level in each of the three dimensions, i.e., Bosetti et al. [24], Ghersi and Hourcade [25], Kim et al. [26], Bataille et al. [27], Köhler et al. [28], Böhringer and Löschel [29], Laitner and Hanson [30], are summarized in Hourcade et al., [23]. These studies are close to the ”ideal model” in Figure 2.1 and will be briefly summarized one by one in the following paragraphs.

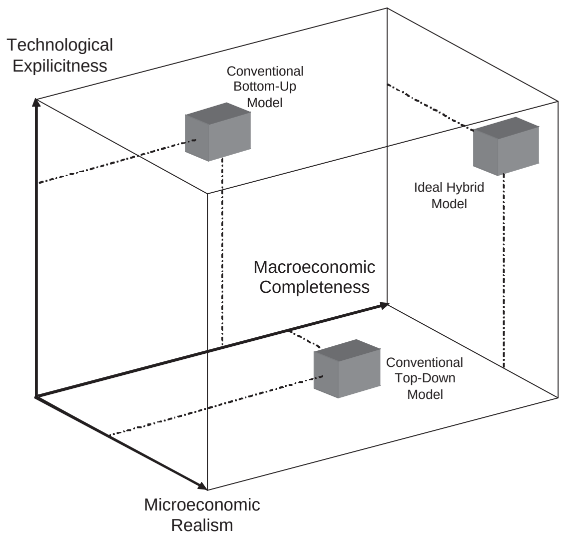


Figure 2.1: Three-dimensional Assessment of Energy-economy Models, [23].

Bosetti et al. [24] introduced a 12-region global hybrid model, WITCH, in which a detailed energy supply sector is incorporated in a Ramsey-type optimal growth model (a neoclassical optimal growth model). The model departs from the other hybrid modeling approaches by considering the carbon strategies of countries in a game-theoretic framework. The model also has the capability of determining the technological progress endogenously using the learning curves and R&D investments.

Ghersi and Hourcade [25] revisit the ”Elephant and Rabbit stew” metaphor (Hogan and Manne [31]) where energy and economy correspond to the rabbit and the elephant, respectively. The metaphor is used in explaining the situations when one of the components constitutes a relatively big portion of the whole, and claims that the whole is much like the big component. Ghersi and Hourcade criticize the general attitude of keeping the non-energy functions of the economy constant when there are significant departures from the reference trends, and propose to adjust the production and utility functions using the information from the energy sector. They developed a general equilibrium model, IMACLIM, which uses an innovation possibility curve to represent the various production possibilities. World Energy Model (WEM), a 21-region bottom-up partial equilibrium simulation model developed by International Energy Agency (IEA), is coupled with a variation of IMACLIM model, IMACLIM-R, in 2008 which is called WEM-ECO [32].

Kim et al. [26] use a modular and flexible integrated assessment framework, O^{bj}ECTS, and an extension of MiniCAM (former version of GCAM developed by Global Change Research Institute) in O^{bj}ECTS framework. They integrate a detailed energy sector representation in a macroeconomic structure where only agriculture and energy markets are cleared. The linkage between energy and the rest of the economy is provided with a simple feedback loop using energy prices.

Bataille et al. [27] use the CIMS model which comprises three submodels, i.e., macroeconomic submodel, energy supply and conversion submodel, and energy demand submodel, working iteratively until an equilibrium is obtained. Bataille et al. also present a survey on estimation of elasticity of substitution and energy efficiency index parameters in climate change policies. Murphy et al. [33] then use CIMS model in order to analyze the implications of emission reduction policies in Canadian industrial sector.

Böhringer and Löschel [29] integrate the bottom-up and top-down approaches for analyzing the economic and environmental effects of the renewable energy in Europe in a unique model which is formulated as a Mixed Complementarity Problem (MCP). Using MCP in integrating top-down and bottom-up modeling approaches was first introduced by Böhringer [34]. In MCP format, it is possible to keep general equilibrium as well as representing the technology-rich structure of the bottom-up modeling using the complementarity relations. Böhringer and Rutherford [35] first present a pedagogic discussion paper on integrating the two approaches using MCP format and then propose an improved solution technique using decomposition, i.e., quadratic programming to solve the bottom-up energy model and complementarity methods to solve the top-down model, [36]. The reader is referred to Kumbaroğlu [37] and Kumbaroğlu and Madlener [38], for two applications of such modeling approach.

AMIGA is a hybrid model which represents a technology-rich energy sector in a CGE framework. It comprises approximately 200 sectors in the United States and 30 in the rest of the world covering 21 world regions including the United States. The model try to obtain equilibrium sequentially using the program blocks of prices, input intensities and market shares, and output. Laitner and Hanson [30] employ AMIGA to analyze the changes in energy efficiency, and technology investments using the health care sector as an example.

Schäfer and Jacoby [39] summarize a three-module model, CGE-MARKAL, for transportation sector where they focus mainly on model calibration. The model integrates the bottom-up model MARKAL and a 12-region global recursive dynamic CGE model, EPPA, using an intermediate module of modal split model. The overall model attains an equilibrium by iterative adjustments between the modules. The reader is referred to [40] by McFarland et al. for another hybrid modeling approach using EPPA in which three new electricity generation options are analyzed by translation of a bottom-up model information to EPPA.

E3MG model, introduced by Köhler et al. [28] is a 20-region dynamic global econometric simulation model including an energy technology module. This hybrid structure allows the model to determine the technical change endogenously. E3MG departs from the other models reviewed in this study by the post-Keynesian, i.e., the growth is demand-led and supply constrained, macroeconomic assumption it employs instead of a general equilibrium approach.

2.4 REVIEW OF THE MOST RELATED STUDIES

The one-sector version of the multi-sector model proposed in our study takes its roots from Manne's ETA-MACRO model, [3]. ETA-MACRO is an energy-economy model which integrates a detailed energy supply module with the economy module, which produces a single output using the factor inputs: capital, labor and energy. The production is described through a constant elasticity of substitution (CES) function. The objective in ETA-MACRO is to maximize the discounted utility of consumers represented with the total discounted consumption. The link between energy and economy modules is provided by the flow of energy consumptions and energy costs between the modules.

Güven [4], Kumbaroğlu [11], Arıkan et al. [41], Kumbaroğlu [42] and Kumbaroğlu et al. [44] are also in the same class of ETA-Macro type models. These models all use the same methodological approach differing marginally in energy sector detail, period length, planning horizon, base year, some macroeconomic assumptions and consideration of environmental aspects.

Güven [4] extends ETA-MACRO in a manner that the model comprises foreign trade. This extension, including a constraint on foreign exchange, increases the representation capability of the model for countries whose economies heavily rely on foreign capital inflows like Turkey. Güven's model is then further extended by Arıkan et al. [41] and Kumbaroğlu [42] by integrating an environment module where the focus was on SO_2 and NO_x emissions. Kumbaroğlu [11] extends the integrated energy-economy-environment models, introduced in [41] and [42], as it determines pollutant abatements and environmental taxes endogenously, i.e., preference rates related to level of pollutant emissions and emission tax are defined and incorporated into the utility function.

In a recent study, Kumbaroğlu et al. [44] analyze the penetration of renewable energy technologies to Turkey's energy system under various emission reduction scenarios. The model used in the study is a variation of the models [11], [41] and [45]. It includes endogenous technological learning and a willingness to pay function which is derived from a pilot survey where Adaman et al. [46] recently conducted a comprehensive survey for revealing the determinants of urban households' willingness to pay for CO_2 emissions in Turkey.

The two-way linkage between the energy and the rest of the economy makes these one-sector optimization models powerful alternatives to those which either employ a pure bottom-up or a pure top-down approach; however, the lack of sectoral details is the main handicap of these models. Then, our main contribution is the integration of sectoral detail into a conventional one-sector optimization model. Aside from its multi-sector structure, our model differs from the former one-sector optimization models in the following aspects:

- Shorter period length,
- Treatment of domestic and foreign goods as imperfect substitutes,
- An up-to-date analysis of the Turkish energy sector,
- A more detailed representation of capital accumulation.

A detailed description for the one-sector version of our multi-sector model is presented in Chapter 4 and mathematical formulation of the model is given in Appendix E.

In addition to aforementioned optimization models, Kumbaroğlu [37] introduces a seven-sector CGE model for Turkey in order to analyze the environmental taxation. The model consists of three energy sectors, i.e., electricity, oil and gas, and solids, and the sectors of transportation, manufacturing and basic industries, services, and others. Kumbaroğlu employs his model in analyzing the environmental taxation and its implications.

Yeldan et al. [43] proposes another CGE model for Turkey, in which the economy is represented by ten aggregated sectors, which are thought to be enough to represent the energy sectors and the sectors critical in GHG pollution. The study mainly focuses on CO_2 emissions. The aggregated sectors in [43] are as follows:

- Agricultural production
- Coal Mining
- Petroleum and Gas
- Refined Petroleum

- Electricity Production
- Cement Production
- Paper Production
- Iron and Steel Production
- Transportation

Yeldan et al. propose two broad categories of policy interventions. In the first category, the production-emission structure of the economy is assumed to remain as it is where reduction in CO_2 emissions is achieved by tax and quota based instruments. In the second category, on the other hand, reductions are achieved by active abatement investment policy.

In conclusion, a great number of energy models have been reviewed in this chapter. Although each model has its own characteristics, energy models have been classified under two distinctive classes in course of time: bottom-up and top-down modeling approaches. Besides the conventional models developed in each class, recent trend is to integrate the two approaches and obtain models possessing energy sector detail as a bottom-up model as well as representing microeconomic foundations as a top-down model. In this thesis, we propose a novel hybrid energy-economy-environment model in which sectoral detail and energy specifics are integrated into a macroeconomic model formulated as an optimization problem.

CHAPTER 3

TURKISH ENERGY SECTOR

This chapter illustrates the general energy outlook of Turkey. It begins with the energy reserves, primary energy production and total energy supply of the country. Then, the general energy balance for 2009 is presented and the energy resources are discussed in detail under four main headings: solid fuels, crude oil and petroleum products, natural gas and power system.

Table 3.1 [47] lists the reserves of all domestic resources which add up to about 1% of the world total. The term ”proven” in Table 3.1 means that the corresponding amounts are estimated with high certainty (at least 90%) and can be produced with the existing technology and current costs. The level of certainty for probable reserves is at least 50%. Possible reserves, on the other hand, has a certainty level of at least 10% and it is not possible to produce these reserves with the existing technology and commercial rates.

Although Turkey is proximate to the countries with high reserves of oil and gas, it has quite low amounts of its own. On the other hand, the country has a large amount of lignite and hard coal reserves. However, Turkish lignites are poor in terms of calorific content. Turkey has also significant amounts of renewable resources such as hydraulic, wind and solar energy. Note that a value is not given for the solar electricity potential in Table 3.1 but recent studies by EİE (General Directorate of Electrical Power Resources Survey and Development Administration), [48], showed that the technical potential of solar electricity is 278 TWh/year. This amount is higher than the electricity demand of Turkey in 2010.

Turkey has to import the bulk of its energy; domestic resources accounted for only 28.57%

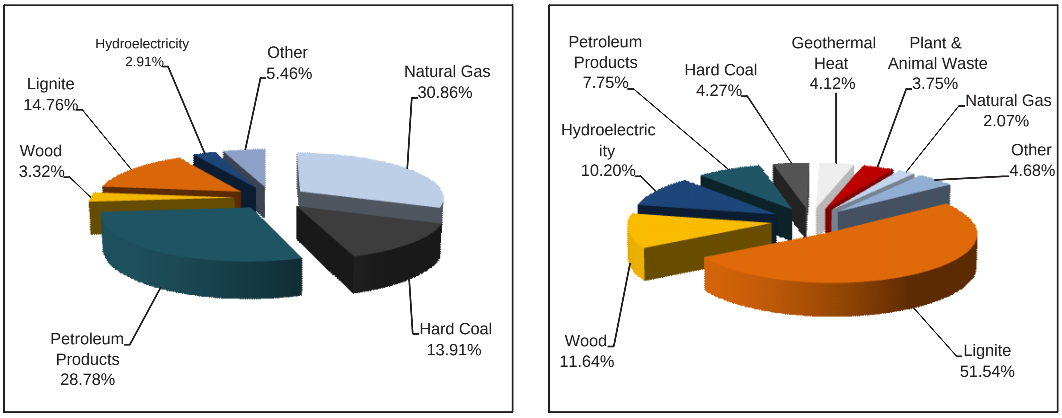
Table 3.1: Primary Energy Reserves, 2009, [47].

	Proven	Probable	Possible	Total
Hard Coal (Million tonnes)	535	432	368	1335
Lignite (Million tonnes)	9837	1344	262	11445
Asphaltite (Million tonnes)	40	29	7	77
Bituminous Coal (Million tonnes)	18			18
Hydraulic				
TWh/Year	129			129
GW/Year	36.6			36.6
Crude Oil (Million tonnes)	42			42
Natural Gas (Billion m3)	7			7
Nuclear (Thousand tonnes)				
Natural Uranium	9			9
Thorium	380			380
Geothermal (GW/Year)				
Electricity	0.1		0.4	0.5
Thermal	3.3		28.2	31.5
Solar				
Electricity (TWh/Year)				
Thermal (Mtoe)				33
Wind				
Electricity (GW)				48
Thermal				
Biomass (Mtoe)				
Electricity				2.6
Thermal				6

of the total supply in 2009. Primary energy production was 30,328 ktoe (thousand tons of oil equivalent) and total primary energy supply was 106,138 ktoe in 2009, [49]. Tables 3.2 and 3.3 show the amounts of primary energy production and supply, respectively, for the period 1999-2009, [47]. These two tables indicate that a significant change has not been observed in the amount of primary energy production, while total energy supply has increased by more than 40% between 1999 and 2009. In other words, Turkey's dependence on imported energy has risen from 62.77% to 71.43% during this period.

Figure 3.1 illustrates the break-down of total primary energy supply as well as domestic production by resource type. As seen in Figure 3.1(a), the shares of petroleum products and natural gas add up to almost 60% of the total primary energy supply whereas lignite constitutes more than half of the domestic energy supply as seen in Figure 3.1(b).

General energy balance of Turkey for 2009, [49], can be seen in Table 3.4 and details of the



(a) Total Primary Energy Supply.

(b) Domestic Energy Supply

Figure 3.1: Break-down of Total Primary Energy Supply and Domestic Energy Supply by Resource Type: Percentages of the Totals, 2009, [50].

total solid fuels supply are tabulated in Table 3.5. General energy balance in original units is also reported in Appendix A (Tables A.1 and A.2). Table 3.4 show that 25,565 ktoe of total primary energy supply is used in the generation and energy sector. As a result, final energy demand in 2009 was 80,574 ktoe which was shared among industrial, transportation and other sectors with consumptions of 25,966 ktoe, 15,916 ktoe and 34,540 ktoe, respectively. Note that 4,153 ktoe of final energy was used for non-energy purposes.

As summarized in Tables 3.3, 3.4 and 3.5, Turkish energy resources consist of solid fuels (lignite,hard coal, asphaltite, wood, animal & plant waste), crude oil, natural gas, hydraulic, geothermal and wind electricity and geothermal and solar heat. These resources are discussed thoroughly in the following sections.

Table 3.2: Primary Energy Production, Original Units, [47].

Year	Hard Coal	Lignite	Asphaltite	Crude Oil	Natural Gas	Hydraulic & Geothermal Electricity	Geothermal Heat	Wind	Solar	Wood	Plant & Animal Waste	Biomass	Total
	kton	kton	kton	kton	M m^3	GWh	ktoe	GWh	ktoe	kton	kton	kton	ktoe
1999	1990	65019	29	2940	731	34759	618	6	236	17642	6184		27659
2000	2392	60854	22	2749	639	30955	648	21	262	16938	5981		26047
2001	2494	59572	31	2551	312	24100	687	33	287	16263	5790		24576
2002	2319	51660	5	2442	378	33789	730	62	318	15614	5609		24282
2003	2059	46168	336	2375	561	35419	784	48	350	14991	5439		23783
2004	1946	43709	722	2276	708	46177	811	61	375	14393	5278		24332
2005	2170	57708	888	2281	897	39655	926	58	385	13819	5127		24549
2006	2319	61484	452	2176	907	44338	898	127	403	13411	4984	2	26580
2007	2462	72121	782	2134	893	36007	914	355	420	12932	4850	14	27455
2008	2601	76171	630	2160	1017	33432	1011	847	420	12264	4883	74	29257

Table 3.3: Total Primary Energy Supply, Original Units, [47].

Year	Hard Coal	Lignite	Asphaltite	Crude Oil	Natural Gas	Hydraulic & Geothermal Electricity	Geothermal Heat	Wind	Solar	Wood	Plant & Anima Waste	Elec. Import	Elec. Export	Biomass	Total
	kton	kton	kton	kton	M m^3	GWh	ktoe	GWh	ktoe	kton	kton	GWh	GWh	kton	ktoe
1999	11362	64049	29	28862	12902	34759	618	21	236	17642	6184	2330	-285		74275
2000	15525	64384	22	31072	15086	30955	648	33	262	16938	5981	3791	-437		80500
2001	11176	61010	31	29661	16339	24100	687	62	287	16263	5790	4579	-433		75402
2002	13830	52039	5	29776	17694	33789	730	48	318	15614	5609	3588	-435		78331
2003	17535	46051	336	30669	21374	35419	784	61	350	14991	5439	1158	-588		83826
2004	18904	44823	722	31729	22446	46177	811	58	375	14393	5278	464	-1144		87818
2005	19421	56571	738	31062	27171	39655	926	59	385	13819	5127	636	-1798		91074
2006	22798	60184	602	31395	31187	44338	898	127	403	13411	4984	573	-2236	2	99642
2007	25388	72317	632	32143	36682	36007	914	355	420	12932	4850	864	-2422	12	107627
2008	22720	75264	630	30756	36928	33270	1011	847	420	12264	4883	789	-1122	74	106348

Table 3.4: General Energy Balance, ktoe, 2009, [49].

	Total Solid	Oil	Natural Gas	Hydroelectricity	Geothermal Electricity	Biomass	Wind	Electricity	Geothermal Heat	Solar	Total
Primary Energy Supply	**37579**	**30565**	**32775**	**3092**	**375**	**9**	**129**	**-63**	**1250**	**429**	**106138**
Domestic Production	22068	2349	627	3092	375	9	129		1250	429	30328
Import (+)	15341	33887	32827					70			82124
Export (-)		6048	649					133			6829
Bunker Sales		657									657
Change in Stocks	170	-441	-30								-301
Statistical Discrepancy		1473									1473
Generation and Energy Sector	**-15169**	**-1225**	**-20089**	-3092	-375		**-129**	**13458**	**1056**		**-25565**
Power Plants	-13933	-1169	-18752	-3092	-375		-129	16754	1056		-19640
Cooking Coal Firms	-1091										-1091
Oil Refinery		-1344	-917					-98			-2360
Domestic Consumption and Loss	-145	1288	-420					-3198			-2474
Final Energy Consumption	**22410**	**29340**	**12685**			**9**		**13395**	**2306**	**429**	**80574**
Industrial Consumption	9773	3539	5507					5962	1056	129	25966
Iron and Steel	2828	9	710					1376	232		5155
Chemical-Petrochemical	132	58	296					385			872
Petrochemical Feedstock		1796									1796
Fertilizer		5	26					20			50
Cement	3896	31	20					478			4426
Sugar	76	15	16					42			149
Non-ferrous metal	33	3	429					165			630
Other Industry	2808	1623	4009					3495	824	129	12888
Transportation		15642	208			9		57			15916
Railway transportation		141						21			162
Sea transportation		525									525
Air transportation		1721									1721
Pipelines			172					27			199
Land transportation		13254	37			9		9			13309
Other Sectors	12638	6006	6970					7376	1250	300	34540
Residential and Services	12637	1640	6970					6956	964	300	29466
Agriculture	1	4366	0,7					420	286		5073
Non-energy		4153									4153

Table 3.5: Total Solid Fuels Balance, ktoe, 2009, [49].

	Hard Coal	Lignite	Asph.	Sec. Coal	P. Coke	Wood	Plant & Animal W.	Total
Primary Energy Supply	**14768**	**15672**	**450**	**8**	**2015**	**3530**	**1136**	**37579**
Domestic Production	1294	15632	476			3530	1136	22068
Import (+)	13119			183	2039			15341
Export (-)								
Bunker Sales								
Change in Stocks	355	40	-26	174	-24			170
Statistical Discrepancy								
Generation and Energy Sector	**-6917**	**-10355**	**-104**	**2292**		**-7**	**-77**	**-15169**
Power Plants	-3409	-10336	-104			-7	-77	-13933
Cooking Coal Firms	-3383			2292				-1091
Oil Refinery								
Domestic Consumption and Loss	-126	-19						-145
Final Energy Consumption	**7851**	**5317**	**345**	**2300**	**2015**	**3523**	**1059**	**22410**
Industrial Consumption	2816	2506	137	300	2015			9773
Iron and Steel	597			2231				2828
Chemical-Petrochemical	48	84						132
Petrochemical Feedstock								
Fertilizer								
Cement	1474	674			1748			3896
Sugar	4	40		32				76
Non-ferrous metal		19			14			33
Other Industry	693	1688	137	37	253			2808
Transportation								
Railway transportation								
Sea transportation								
Air transportation								
Pipelines								
Land transportation								
Other Sectors	5036	2811	208	0.6		3523	1059	12638
Residential and Services	5035	2811	208	0.6		3523	1059	12637
Agriculture	1							1
Non-energy								

3.1 SOLID FUELS

3.1.1 HARD COAL

Turkey has a reserve of 1,335 million tons of hard coal, 535 million tons of which is proven. Hard coal is extracted from the mines in Zonguldak and calorific value of this coal is 6200-

7200 kcal/kg. Most of the extraction is made by Turkish Hardcoal Enterprise (TTK). It was the main primary energy resource till mid 1980s. However, with the development of alternative sources of energy, decrease in crude oil prices and the liberalization of Turkish economy, competitive power of TTK has decreased in recent decades.

Main consumption areas of hard coal are power plants and iron-steel industry. It is also used in other industries such as cement, tea, sugar, etc., and in residential heating. Besides the domestic production, Turkey imports hard coal, which is much cheaper than the domestic production. Hard coal imports has reached to 20.2 million tons in 2009, while it was 5.6 million tons in 1990.

3.1.2 LIGNITE

Lignite (brown coal) is a type of coal which is mostly used for electricity generation due to its low calorific value. It is extracted in many regions of Turkey such as Afşin-Elbistan, Soma, Tunçbilek, Seyitömer, Beypazarı and Kangal. Lower and upper calorific values of Turkish lignites are 1000 kcal/kg and 4200 kcal/kg, respectively, while most of the reserves lie in the lower end of this interval. With a production of around 76 million tons (see Table 3.2 for lignite production amounts), Turkey is in the first ten countries ranked according to lignite production. 50% of lignite production is realized by Turkish Coal Enterprises (TKİ), where the remaining amount is extracted by private sector and Electricity Generation Company Incorporated (EÜAŞ), [50].

3.1.3 ASPHALTITE

Asphaltite is a bituminous energy resource with a calorific value of about 5300 kcal/kg. Turkey has a reserve of 76 million tons of asphaltite and most of the asphaltite is extracted in Şırnak by Şırnak Special Provincial Administration. Amount of asphaltite produced between the years 1999-2009 can be seen in Table 3.2. Due to the low share of asphaltite in energy supply, it is included in hard coal statistics in our computations.

3.1.4 SECONDARY COAL

Secondary coal is derived from primary coal by some transformation processes, e.g., from coke ovens, blast furnaces or gas works. Coke and briquette are two examples of secondary coal which take place in general energy balance of Turkey as seen in Table 3.4. Secondary coal is included in hard coal in our computations.

3.1.5 PETROLEUM COKE

Petroleum coke is a carbon rich solid derived from cracking processes. Unlike coke which is derived from coal, petroleum is used in petroleum coke production. It is mostly used in cement industry and whole demand is satisfied by imports. As seen in Table A.1, Turkey has imported 2.7 million tons of petroleum coke in 2009, most of which was used in cement industry. Petroleum coke is included in petroleum products instead of solid fuels in our model.

3.1.6 ANIMAL AND PLANT WASTE, AND WOOD

Animal and plant waste, and wood are used in residential heating mostly in rural areas. They are loosing their importance year by year, i.e., supply of animal and plant waste and wood were 17.87 and 8.03 million tons in 1990, respectively, while these values are 11.76 and 4.86 million tons in 2009, respectively.

3.2 CRUDE OIL AND PETROLEUM PRODUCTS

Crude oil and petroleum products are the main source of energy in Turkey, as in most of the countries over the world, due to the ease of transportation and high energy density. Except a (relatively) small amount of crude oil (4.15 million tones), which is used in some chemical products, all production is consumed for energy demand, mostly after being transformed into fuel oil and gasoline. Declared total oil reserves of the world is around 1200 trillion barrels, [51], two third of which is held by the Organization of the Petroleum Exporting Countries (OPEC). Turkey, however, has a reserve of only 42 million tons of crude oil, nearly all of which is in Southeastern Anatolia. When compared to world oil reserves, this amount is negligible . In fact, domestic reserves cannot meet even two-years of demand without imports and will be depleted in less than 20 years with the current level of domestic production.

In 2009, Turkey has imported 33.9 million tons of crude oil and petroleum products besides the domestic production. This amount approximates to 40% of the total energy imports and more than one third of the total energy supply.

Domestically produced crude oil is refined in the refineries located in Batman, İzmit, İzmir and Kırıkkale. İzmit, İzmir and Kırıkkale refineries also refine imported crude oil which arrives in İzmit and İzmir via the refinery ports and in Kırıkkale via the pipeline between Ceyhan and Kırıkkale. There are two international pipelines, Baku-Tbilisi-Ceyhan and Kirkuk-Ceyhan, used for imported crude oil transportation. The former was completed in 2006 and the latter has been used sporadically and in very low utilization since the UN embargo on Iraq laid after Iraq's invasion of Kuwait in 1990.

Russia is the country from which 41% of the total crude oil imports is supplied. Iran, S. Arabia, and Azerbaijan follow Russia with the shares of 23%, 15% and 12%, respectively, [50].

3.3 NATURAL GAS

Natural gas has become a crucial element in energy consumption bundle of Turkey (nearly one third of total energy supply) with the import agreements after mid 1990s. Although total supply of natural gas was negligible up to mid 1980s, it has increased from 3.4 billion m^3 in 1990 to 32.8 billion m^3 in 2009. More than 60% of total natural gas supply in 2009 (see Table 3.4) was consumed for generating electricity and remaining amount is used in industry and by residential consumers. Natural gas reserves of Turkey is exiguous (see Table 3.1) as is the case for crude oil mentioned in the previous section. Domestic production is only 2% of the total supply in 2009 and reserves would satisfy only a few months of demand without imports.

There are two ways of importing natural gas: through pipelines from Russia, Iran and Azarbaijan or in the form of liquified natural gas (LNG) from Nigeria and Algeria by sea transportation.

With the increasing importance of natural gas, countries those have huge reserves gained politic and strategic advantages, which has become more apparent during the recent gas crises. European Union (EU) countries which also import a considerably high amount of natural gas (50% of their demand) hastened their studies on energy security. Energy security studies in Turkey are continuing under the responsibility of Ministry of Energy and Natural Resources (MENR) of Turkey . Based on these studies, use of hydraulic, renewable, nuclear and coal energy is expected to increase in order to decrease the effects of probable crises in the supply of natural gas and crude oil which are under the control of certain countries. However, long-term gas purchase contracts (see Table 3.6) and the fact that the number of natural gas power plants has increased too much makes it hard to introduce compulsory policies.

Table 3.6: Natural Gas Purchase Contracts, [50].

Contracts	Amount (Billion m^3)	Date of Approval	Duration	Status
Russia	6	1986	25	Active
Algeria (LNG)	4	1988	20	Active
Nigeria (LNG)	1.2	1995	22	Active
Iran	10	1996	25	Active
Russia (Blacksea)	16	1997	25	Active
Russia (West)	8	1998	23	Active
Turkmenistan	16	1999	30	-
Azerbaijan	6.6	2001	15	Active

3.4 POWER SYSTEM

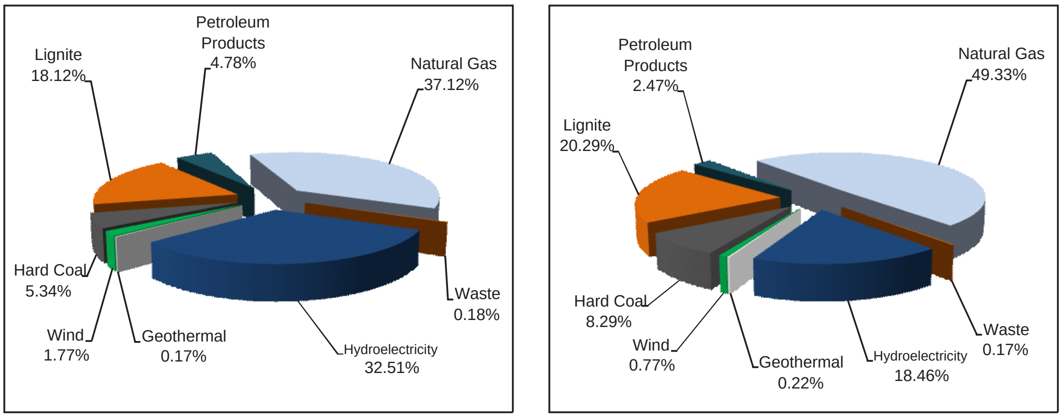
3.4.1 A SHORT HISTORY OF THE TURKISH POWER SYSTEM

Turkish electricity industry dates back to a 2 KW water mill built in Tarsus in 1902. The first extensive power station, İstanbul Silahtarağa Power Station, was built in 1912. By the year 1923, installed capacity had reached to 33 MW and gross generation to 45 million kWh. State organized electricity administration began with the establishment of ETİBANK in 1935. Installed capacity increased rapidly by the contributions of General Directorate of Mineral Research and Exploration (MTA), General Directorate of Electrical Power Resources Survey and Development Administration (EİE), İller Bank and power generation utilities built by General Directorate of State Hydraulic Works (DSİ) after 1948. Turkish Electricity Authority (TEK) was established in 1970 to control the disordered sector (with an installed capacity of 2234.9 MW and a gross generation of 8.6 GWh) and it took over all the facilities from municipalities and unions in 1982. In 1984, monopoly of TEK was lifted and necessary legal regulations were made which enabled private companies to generate, transmit and distribute electricity. TEK is taken under the scope of privatization and is split into two state-owned enterprises, Turkish Electricity Transmission Company (TEİAŞ) and Turkish Electricity Distribution Company (TEDAŞ), in 1993. Electricity Market Law issued in 2001 comprises the establishment of Energy Market Regulatory Authority (EPDK) and rights and responsibilities of real and legal persons related with the generation, transmission, distribution, wholesale and retail sale of electricity, [52].

3.4.2 CURRENT PROFILE OF THE TURKISH POWER SYSTEM

As a developing country, electricity demand of Turkey has been growing rapidly by industrialization and urbanization. Electricity demand of Turkey is almost completely met by domestic production (which does not mean by domestic resources, i.e., Turkish power sector highly depends on imports of fuels used in power stations as mentioned in the previous section). Imports and exports of electricity are in negligible amounts. Table 3.7 shows the installed capacity for years 1984-2009 and Table 3.8 shows the gross generation volumes for the same period, [53].

Tables 3.7 and 3.8 indicate that diversity in electricity generation has shown great improvement in the last 20 years. Lignite and fuel oil power plants together with hydroelectricity were constituting almost all installed capacity with the shares 31%, 20% and 46%, respectively, in 1984. In 2009, however, these shares decreased to 18%, 5% and 33%, as seen in Figure 3.2(a), although installed capacities of these power stations increased gradually. During this period, most significant evolution has been observed in natural gas power plants. In 1984, there was no natural gas power station generating electricity, but especially after the natural gas agreements mentioned in Section 3.3, share of natural gas power stations has reached to 37% in terms of installed capacity and 49% in terms of electricity production by year 2009 as



(a) Installed Capacity.

(b) Gross Generation

Figure 3.2: Break-down of Installed Capacity and Gross Generation by Plant Type: Percentages of the Totals, 2009, [53].

illustrated in Figure 3.2.

Table 3.7: Installed Capacity, 1984-2009, MW, [53].

	Hard Coal	Imp. Coal	Lignite	Petrol. Prod.	Natural Gas	Waste	Total Thermal	Hydro.	Geo.	Wind	Total
1984	220		2622	1728			4569	3875	18		8462
1985	220		3182	1728	100		5229	3875	18		9122
1990	332		5246	1748	2210		9536	6764	18		16318
1995	326		6456	1353	2925	14	11074	9863	18		20954
2000	335	145	6919	1586	7044	24	16053	11175	18	19	27245
2001	335	145	6966	2000	7154	24	16623	11673	18	19	28314
2002	335	145	6959	2400	9702	28	19569	12241	18	19	31827
2003	335	1465	6904	2733	11510	28	22974	12579	15	19	35568
2004	335	1510	6905	2569	12798	28	24145	12645	15	19	36805
2005	335	1651	7586	2506	13790	35	25902	12906	15	20	38823
2006	335	1651	8665	2400	14266	41	27357	13063	23	59	40502
2007	335	1651	8671	1994	14578	43	27272	13395	23	146	40836
2008	335	1651	8109	2353	15087	60	27595	13829	30	364	41817
2009	2391		8110	2140	16617	82	29340	14553	77	792	44762

Electricity market law, issued in 2001, foresees the conduction of market activities predominantly by the private organizations. However, it requires time for the market to reach to a

Table 3.8: Gross Generation, 1984-2009, GWh, [53].

	Hard Coal	Imp. Coal	Lignite	Petrol. Prod.	Natural Gas	Waste	Total Thermal	Hydro.	Geo.	Wind	Total
1984	706		9413	7047			17165	13426	22		30614
1985	710		14318	7082	58		22168	12045	6		34219
1990	621		19561	3942	10192		34315	23148	80		57543
1995	2232		25815	5772	16579	222	50621	35541	86		86247
2000	3176	643	34367	9311	46217	220	93934	30879	76	33	124922
2001	2706	1340	34372	10366	49549	230	98563	24010	90	62	122725
2002	2646	1447	28056	10744	52497	174	95563	33684	105	48	129400
2003	2694	5969	23590	9196	63536	116	105101	35330	89	61	140581
2004	2478	9520	22450	7670	62242	104	104464	46084	93	58	150698
2005	2965	10281	29946	5483	73445	122	122242	39561	94	59	161956
2006	3074	11143	32433	4340	80691	154	131835	44244	94	127	176300
2007	3290	11847	38295	6527	95025	214	155196	35851	156	355	191558
2008	3291	12567	41858	7518	98685	220	164139	33270	162	847	198418
2009	3335	12813	39537	4804	96095	340	156924	35958	436	1495	194813

liberal and competitive structure since most of the activities are currently performed by state-owned utilities. Tables 3.9 and 3.10 show the change in the distribution of installed capacity and generation amounts for state-owned and private companies from 1984 to 2009 where Table 3.11 tabulates the detailed distribution of installed capacity for the period 1984-2005. Note that although there is a significant increase in the share of the production companies and auto-producers, their share is yet 46% of the total installed capacity in 2009.

Table 3.9: Distribution of Installed Capacity by Electricity Utilities, 1984-2009, MW, [53].

	State-owned Plants				Private Plants			
	Thermal	Hydro.	Total	Share (%)	Thermal	Hydro.	Total	Share (%)
1984	3545	3644	7190	85.0	1041	231	1272	15.0
1990	8264	6465	14729	90.3	1289	299	1588	9.7
1995	9651	9208	18858	90.0	1441	655	2096	10.0
2000	11275	9977	21252	77.9	4795	1217	6012	22.1
2001	10955	10109	21063	74.3	5686	1583	7269	25.7
2002	10950	10109	21058	66.1	8636	2151	10788	33.9
2003	10803	10990	21793	61.2	12186	1607	13794	38.8
2004	10795	10995	21790	59.2	13365	1670	15034	40.8
2005	11475	11110	22585	58.1	14442	1817	16259	41.9
2006	12555	11161	23716	58.5	14880	1969	16849	41.5
2007	12525	11350	23875	58.6	14711	2192	16902	41.4
2008	12525	11456	23981	57.3	15070	2766	17836	42.7
2009	12525	11678	24203	54.1	16809	3755	20564	45.9

Table 3.10: Distribution of Gross Generation by Electricity Utilities, 1984-2009, GWh, [53].

	State-owned Plants				Private Plants			
	Thermal	Hydro.	Total	Share (%)	Thermal	Hydro.	Total	Share (%)
1984	14426	12260	26686	87.2	2761	1167	3928	12.8
1990	30698	22156	52854	91.9	3697	992	4689	8.1
1995	45090	33105	78195	90.7	5617	2436	8053	9.3
2000	65462	27772	93234	74.6	28547	3140	31688	25.4
2001	65954	20409	86362	70.4	32699	3664	36362	29.6
2002	51028	26304	77332	59.8	44640	7428	52067	40.2
2003	33070	30027	63097	44.9	72120	5364	77484	55.1
2004	27349	40669	68017	45.1	77208	5473	82681	54.9
2005	38416	35046	73462	45.4	83921	4574	88494	54.6
2006	46037	38679	84716	48.1	85892	5691	91584	51.9
2007	61345	30979	92324	48.2	93961	5270	99231	51.8
2008	69297	28419	97717	49.2	94842	5859	100701	50.8
2009	61120	28330	89450	46.1	95120	9490	104609	53.9

Turkey has no nuclear plants although building one has been on the agenda since 1965. In 2010, a contract was signed with Russia for construction of a four-unit power plant in Akkuyu with a total capacity of 4800 MW. Besides this, constructing two more plants, one in Sinop and one in the Marmara Region, is on the government's agenda.

The geothermal potential of Turkey is 31500 MW, only 1500 MW of which is suitable for electricity generation. Recent studies indicate that wind energy potential is 48000 MW, 8000 MW of which is in the highly-efficient category. There are also hundreds of potential sites for hydro power, though most of these can only support small plants. In addition, the technical potential for solar electricity is estimated as 278 TWh/year, [48]. However, Turkey has not been adequately benefiting from the renewable resources, i.e., less than 40% of hydraulic potential has been utilized, wind energy is just in its initial phase and companies are waiting for the government to reduce the barriers to solar electricity.

Table 3.11: Detailed Distribution of Installed Capacity by Electricity Utilities, 1984-2005, MW, [53].

	EÜAŞ	Affiliated Partnerships of EÜAŞ	In the Privatization Scope	Concess-inary Companies	Auto-producers	Production Companies	Mobile Power Plants	Total
1984	7190			324	948			8462
1985	7795			324	1003			9122
1986	8789			328	998			10115
1987	11014			378	1103			12495
1988	12984			378	1158			14521
1989	14240			378	1174	16		15808
1990	14729			378	1194	16		16318
1991	15317			662	1205	26		17209
1992	16800			669	1222	26		18716
1993	18280			693	1330	35		20338
1994	18649			716	1459	35		20860
1995	15574	3284		716	1345	35		20954
1996	15621	3284		716	1429	199		21249
1997	15786	3284		716	1777	329		21892
1998	16279	3284		716	2307	768		23354
1999	17835	3284		610	2655	1655	79	26119
2000	17968	3284		610	2996	1985	91	27264
2001	17779	3284		610	3374	2338	297	28332
2002	17774	3284		1120	3736	4659	623	31846
2003	17959	2154	1680		4542	7806	796	35587
2004	17956	2154	1680		4380	9224	780	36824
2005	18751	2154	1680		4062	10797	750	38844

CHAPTER 4

MULTI-SECTOR MODEL

The multi-sector model proposed in this study takes its roots from Güven [4] which comprises a reformulation of Alan Manne's model [3] to include foreign trade. The inclusion of foreign trade serves to enhance the representative capability of the model for economies that rely on foreign capital inflows for growth. Güven's model was further extended in [41] and [42], by integrating an environment module where the focus was on SO_2 and NO_x emissions. These models all assume a one-sector economy. That is, there is a single production-function that generates gross output using the factors of labor, capital, intermediates and alternative sources of energy.

In order to understand the basics of the models, which employ the approach in [3], [4] and their extensions, a one-sector model is built as a first step using the up-to-date data and considering the current profile of the Turkish energy system. Figure 4.1 illustrates the schematic representation of this model. As seen in Figure 4.1, the model comprises energy and macroeconomic modules. Note that, although the model includes a third module (environment module); an explicit environment module has not been shown in the figure since the environmental variables are determined by product of energy generation or consumption activities.

Four main energy inputs are assumed to take place in the gross output function, which are solid fuels, electricity, petroleum products and natural gas. Note that solid fuels consist of wood, lignite and hard coal, and there exist nine distinct technologies of generating electricity: coal, natural gas, lignite, petroleum products, nuclear, geothermal, wind, solar and hydraulic. The model also allows transactions with the rest of the world. That is, imports of consumption, intermediate and investment goods, and exports are explicitly represented in the model. Capital accumulation is triggered by the investments, and production in the economy is a function of all factor inputs: capital, labor, intermediate goods and energy inputs. The link between the energy and macroeconomic modules is provided by the energy flows into the macroeconomic module as well as energy costs. Supply-demand equilibrium is established by computing a utility-maximizing optimum, that is, the objective of the model is to maximize discounted sum of annual utilities over the planning horizon where annual utility in a year is denoted by a function of the consumption amounts in the given year. The exogenously specified growth of labor and technical progress are the main drivers of the model.

The mathematical formulation for the one-sector model, including sets, variables and parameters of the model, can be seen in Appendix E. Note that this model differs from the former one-sector models with the one-year period length instead of a period length of three or five-years and its treatment of foreign and domestic consumption goods as imperfect substitutes as well as representing the recent profile of Turkish energy system in terms of supply and demand.

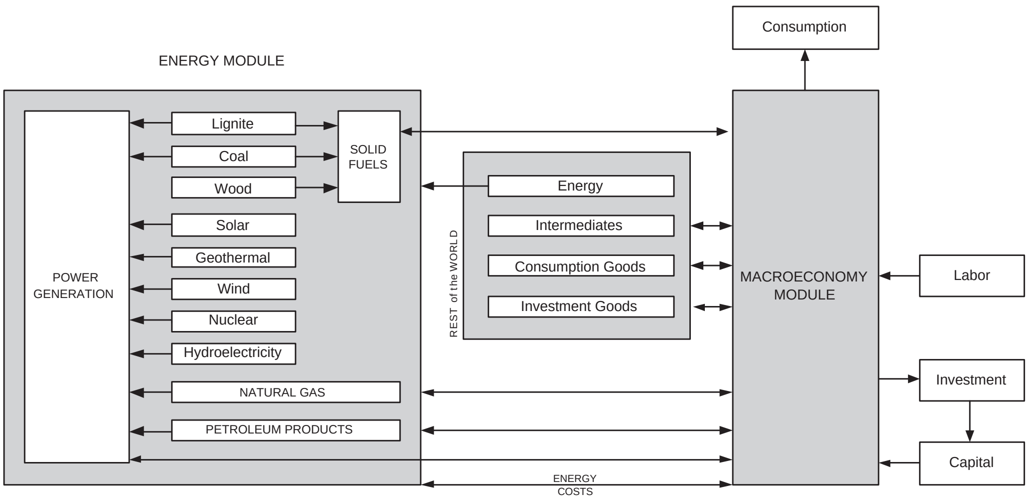


Figure 4.1: Schematic Representation of the One-sector Model.

The multi-sector model, on the other hand, disaggregates the traditional one sector macroeconomic module into five sectors, i.e., *Agriculture*, *Industry: Energy-intensive*, *Industry: Other*, *Services* and *Transportation* and specifies alternative energy supply activities. Accordingly, economic activity takes place in five sectors, which will be denoted by indices i and j interchangeably in the rest of the thesis. This disaggregation seeks to represent the energy and growth dynamics of the economy on the whole. The architecture of the multi-sector model is illustrated in Figure 4.2 for two-sectors: Sector A and Sector B, without loss of generality and for the sake of simplicity. The representation $A \rightarrow B$ denotes the demand of good A by sector B. As seen in this figure, each sector has its own macroeconomic module and explicitly defined energy activities. Furthermore, the model clearly represents the intersectoral flows of intermediate and investment goods as well as the interactions of each sector with the rest of the world.

A distinctive feature of the model is to treat all sectoral goods as imperfect substitutes of corresponding imports. This serves to provide a detailed representation of foreign trade by splitting investment and consumption activities into their domestic and imported components. Unlike other goods, domestic energy resources compete with imported fuels as perfect substitutes.

One of the main difficulties in extending the one-sector model into a multi-sector model is in preparing the data set for each sector. It is relatively easy to obtain aggregated data for the entire economy; sectoral data however needs to be reorganized to meet the requirements of the model. The details of preparing sectoral data are explained in Appendices B and C for energy and macroeconomic modules, respectively.

Another important challenge in the multi-sector model is the calculation of sector specific energy costs. In the one-sector model, total energy cost is calculated by simply adding together all costs incurred from energy related activities. In the multi-sector model, on the other hand, average end-use prices should be determined endogenously in the model since it is not always possible to distinguish the actual source of a final energy consumption. This challenge arises in two cases, i.e., energy options with different cost figures providing their outputs into a single pool as is the case in power industry or the data set without required detail as is the case for non-electric use of lignite. Note that determining average end-use prices endogenously in the model increases the number of non-linear equations in the constraint set which makes it more difficult to obtain the optimal solution.

Energy is treated in production as an input factor whereas in consumption it is treated as an intermediate good. Moreover, energy sector is represented with a separate energy module rather than being represented as a production sector. These treatments lead to difficulties in maintaining accounting balances, which were overcome by modifying the Social Accounting Matrix. This will be clarified in the next section.

Mathematical formulation of the multi-sector model as well as full lists of the variables and parameters used in the model can be seen in Appendix F. Note that this appendix does not include the sets since they are almost the same as those presented in Appendix E.1. GAMS code of the model is also given in Appendix I which would be more comprehensible to the reader owing to self-defining variables used in the code.

4.1 MACROECONOMIC MODULE

The objective of the model is to attain a solution point which is computed by maximizing the discounted sum of annual utilities over the planning horizon as a function of consumption goods and services produced or imported by five sectors. Then, the objective function of our model can be expressed as follows:

$$\max \sum_{t=t_0}^{\infty} \Delta_t \left[\prod_{i=1}^{n} log((C_{it}^F)^{sc_i^f} (C_{it}^D)^{sc_i^d})^{\theta_i} \right] \tag{4.1}$$

$$with \ \sum_{i=1}^{n} \theta_i = 1 \ \ and \ \ sc_i^f + sc_i^d = 1 \ \ for \ \ all \ \ i,$$

which is equivalent to

$$\max \sum_{t=t_0}^{\infty} \Delta_t \left[\sum_{i=1}^{n} \theta_i log((C_{it}^F)^{sc_i^f} (C_{it}^D)^{sc_i^d}) \right] \tag{4.2}$$

$$with \ \sum_{i=1}^{n} \theta_i = 1 \ \ and \ \ sc_i^f + sc_i^d = 1 \ \ for \ \ all \ \ i,$$

where C_{it}^D and C_{it}^F denote the final consumption of domestic and foreign goods (which are imperfect substitutes), produced in sector i and period t. θ_i is the share parameter for sector i and $\Delta_t = \frac{1}{(1+\delta)^{t-t_0}}$, where δ and t_0 denote the annual discount factor and base-year, respectively. The condition $\sum_{i=1}^{n} \theta_i = 1$ assures that the utility function is homogeneous of degree 1. sc_i^d and sc_i^f are share parameters.

The model has a planning horizon of finite duration. Then, the objective function can be

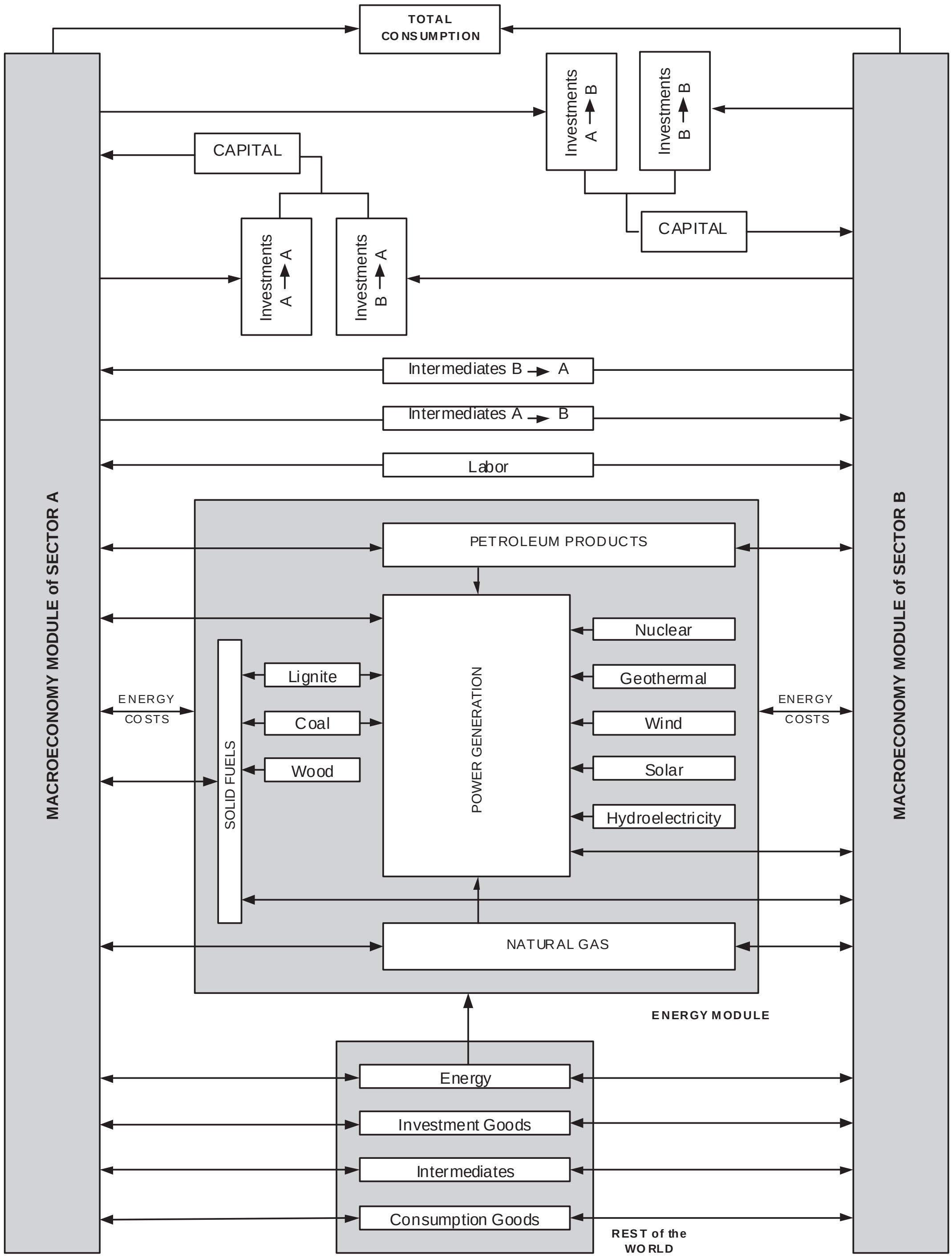


Figure 4.2: Schematic Representation of the Multi-sector Model.

rewritten as follows assuming that the consumption beyond the final period T grows with a post-horizon growth rate of g.

$$\max \sum_{t=t_0}^{T} \Delta_t \left[\sum_{i=1}^{n} \theta_i log((C_{it}^F)^{sc_i^f} (C_{it}^D)^{sc_i^d}) \right] + \frac{\Delta_{(T+1)}(1+g)}{1-\frac{(1+g)}{(1+\delta)}} \sum_{i=1}^{n} \theta_i log((C_{iT}^F)^{sc_i^f} (C_{iT}^D)^{sc_i^d})$$
$$with \ \sum_{i=1}^{n} \theta_i = 1 \ \ and \ \ sc_i^f + sc_i^d = 1 \ \ for \ \ all \ \ i, \tag{4.3}$$

where the second group of terms in Equation 4.3 extends the end of horizon consumption indefinitely into the future in order to eliminate end-of-horizon bias.

Recall from Section 2.1.2 that, SAM is a matrix representation of national accounting balances in equilibrium for a particular point in time. For each sector or product in the SAM; row sum, which denotes the total revenue received from the product, is equal to the corresponding column sum which represents the cost of inputs used in production. Energy is treated as an intermediate good and an input to production activities in our model. This formulation complicates the accounting to an extend and produces a modified SAM of the economy, that is summarized in Table 4.1.

Table 4.1: Structure of the Database for the Macroeconomic Module (modified SAM).

	Sector 1	...	Sector i	...	Sector n	Cons.	Invest.	ROW
Sector 1	$Inter_{11t}$	...	$Inter_{1it}$	...	$Inter_{1nt}$	C_{1t}	$\sum_i Invest_{1it}$	X_{1t}
$\vdots$	$\vdots$		$\vdots$		$\vdots$	$\vdots$	$\vdots$	$\vdots$
Sector j	$Inter_{j1t}$	...	$Inter_{jit}$	...	$Inter_{jnt}$	C_{jt}	$\sum_i Invest_{jit}$	X_{jt}
$\vdots$	$\vdots$		$\vdots$		$\vdots$	$\vdots$	$\vdots$	$\vdots$
Sector n	$Inter_{n1t}$	...	$Inter_{nit}$	...	$Inter_{nnt}$	C_{nt}	$\sum_i Invest_{nit}$	X_{nt}
Dom. Energy	EC_{1t}^D	...	EC_{it}^D	...	EC_{nt}^D			
Value-Added	VA_{1t}	...	VA_{it}	...	VA_{nt}			
ROW	EC_{1t}^F M_{1t}	... ...	EC_{it}^F M_{it}	... ...	EC_{nt}^F M_{nt}			

VA_{it} in Table 4.1 stands for value-added created in sector i; $Inter_{jit}$ is the demand for good j in sector i and year t. EC_{it} is the energy cost incurred in sector i. X_{jt} and M_{it}, given in the rest-of-the-world (ROW) row and column, represent sectoral exports and imports, respectively. $Invest_{jit}$ is investment good produced in sector j and demanded by sector i. Superscripts D and F indicate the domestic and imported components of the associated variables.

Gross output in sector i in period t, is:

$$Y_{it} = \sum_{j=1}^{n} Inter_{jit} + VA_{it} + EC_{it}^{D} + er_t \cdot EC_{it}^{F} \qquad \forall i, t \qquad (4.4)$$

where er is the real exchange rate. The following constraint assures that the total revenue received from the sales of product i is equal to the total cost of inputs used in product i's supply:

$$\sum_{j=1}^{n} Inter_{ijt} + C_{it} + \sum_{j} Invest_{ijt} + er \cdot (X_{it} - M_{it})$$
$$= \sum_{j=1}^{n} Inter_{jit} + VA_{it} + EC_{it}^{D} + er \cdot EC_{it}^{F} \qquad \forall i, t \qquad (4.5)$$

Consumption, intermediates and investments for each sector are the sum of foreign and domestic components:

$$C_{it} = C_{it}^{D} + er \cdot C_{it}^{F} \qquad \forall i, t \qquad (4.6)$$

$$Inter_{ijt} = Inter_{ijt}^{D} + er \cdot Inter_{ijt}^{F} \qquad \forall i, j, t \qquad (4.7)$$

$$Invest_{ijt} = Invest_{ijt}^{D} + er \cdot Invest_{ijt}^{F} \qquad \forall i, j, t \qquad (4.8)$$

Imports of good i is given as:

$$M_{it} = C_{it}^{F} + \sum_{j=1}^{n} Invest_{ijt}^{F} + \sum_{j=1}^{n} Inter_{ijt}^{F} \qquad \forall i, t \qquad (4.9)$$

and the total import bill is the sum of sectoral imports and imported energy:

$$TotM_t = \sum_{i=1}^{n} (M_{it} + EC_{it}^{F}) \qquad \forall t \qquad (4.10)$$

The next group of constraints ensures that total exports equal the sum of sectoral exports and NRH, the "Final Consumption Expenditure of Non-Resident Households on the Economic Territory" which is an item in the national accounts. Hence we have:

$$TotX_t = \sum_{i=1}^{n} X_{it} + NRH_t \qquad \forall t \qquad (4.11)$$

GDP_t is the sum of sectoral value-added and NRH_t:

$$GDP_t = \sum_{i=1}^{n} VA_{it} + NRH_t \qquad \forall t \qquad (4.12)$$

The production in each sector is a function of all factor inputs to production:

$$Y_{it} = f_i(K_{it}, L_{it}, ENERGY_{it}) \qquad \forall i, t \qquad (4.13)$$

where f denotes the production function, K_{it} is the capital stock and, L_{it} is the labor input to sector i and $ENERGY_{it}$ represents the aggregate energy input. We compute annual production as the sum of the "stock" inherited from the previous year and the newly added "flow" of this year:

$$Y_{it} = YN_{it} + \lambda_i^Y \cdot Y_{i,t-1} \qquad \forall i, t > t_0 \qquad (4.14)$$

where λ_i^Y is the stock survival ratio for the gross output in sector i. This convention is adopted for all macro-economic variables with "N" appended to any variable to indicate the associated "flow".

The incremental gross output in sector i is computed as:

$$YN_{it} = \frac{\gamma_{it}[\alpha_i(KN_{it}^{sk_i} LN_{it}^{sl_i})^{\rho_i} + (1-\alpha_i)(EN_{it}^{se_i} PN_{it}^{sp_i} NN_{it}^{sng_i} SN_{it}^{ss_i})^{\rho_i}]^{(\frac{1}{\rho_i})}}{(1 - IntToY_{it})}$$

$$\forall i, t > t_0 \qquad (4.15)$$

Note that the first aggregate in the gross output function represents the value added and the second one represents the energy inputs. Since the intermediate inputs are treated separately, the right hand side of Equation 4.15 is divided by one minus share of intermediates, $IntToY_{it}$, which is computed as follows:

$$IntToY_{it} = \frac{\sum_j Inter_{jit}}{Y_{it}} \qquad \forall i, t \qquad (4.16)$$

$\rho_i = \frac{(\sigma_i - 1)}{\sigma_i}$ where σ_i is the elasticity of substitution for sector i. E_{it} denotes the demand for electricity and P_{it}, N_{it}, S_{it} denote the non-electric demand for petroleum products, natural gas and solid fuels, respectively, by sector i in year t. The superscripts in Equation 4.15 denote share parameters. The stock-flow representation allows substitution only among the incremental variables, that is, Equation 4.15 is written in terms of EN_{it}, PN_{it}, NN_{it}, SN_{it}.

All factor stocks are computed as:

$$INPUT_{it} = INPUTN_{it} + \lambda_i^{INPUT} \cdot INPUT_{i,t-1} \qquad \forall i, t > t_0 \qquad (4.17)$$

where $INPUT \in \{K,\ L,\ E,\ P,\ N,\ S\}$.

Total labor, $TotL_t$, is specified exogenously while the sectoral labor inputs, L_{it}, are determined endogenously.

$$TotL_t = \sum_{i=1}^{n} L_{it} \qquad \forall t \qquad (4.18)$$

Intersectoral flows are determined as in Equations 4.19 and 4.20, as fixed proportions of the sectoral output, i.e., intermediate goods and aggregate of the rest of the factor inputs are treated as they are determined by a Leontief production function.

$$\underline{Int_t} \cdot st^d_{ji} \cdot Y_{it} \leq Inter^D_{jit} \leq \overline{Int_t} \cdot st^d_{ji} \cdot Y_{it} \qquad \forall i, j, t \qquad (4.19)$$

$$\underline{Int_t} \cdot st^f_{ji} \cdot Y_{it} \leq Inter^F_{jit} \leq \overline{Int_t} \cdot st^f_{ji} \cdot Y_{it} \qquad \forall i, j, t \qquad (4.20)$$

where share parameters are computed from base year intersectoral flows as follows:

$$st^d_{ji} = \frac{Inter^D{}_{jit_0}}{Y_{it_0}} \qquad \forall i, j \qquad (4.21)$$

$$st^f_{ji} = \frac{Inter^F{}_{jit_0}}{Y_{it_0}} \qquad \forall i, j \qquad (4.22)$$

and $\underline{Int_t}$ and $\overline{Int_t}$ define an interval that allows substitution of intermediate goods among sectors.

Incremental capital is a Cobb-Douglas aggregate of sectoral investments of the current and previous year. Employing a Cobb-Douglas function in capital allows for substitution in sector i among investment goods produced in all sectors.

$$KN_{it} = \mu_i \prod_j \Big(\sum_{t-1 \leq t' \leq t} \frac{1}{2} Invest^D{}_{j,i,t'} \Big)^{sv^d_{ji}} \cdot \Big(\sum_{t-1 \leq t' \leq t} \frac{1}{2} Invest^F{}_{j,i,t'} \Big)^{sv^f_{ji}} \qquad \forall i, t > t_0. \qquad (4.23)$$

where share parameters are computed from base year investment values as follows:

$$sv^{d}_{ji} = \frac{Invest^{D}_{jit_0}}{\sum_{j'} Invest_{j'it_0}} \qquad \forall i, j \tag{4.24}$$

$$sv^{f}_{ji} = \frac{Invest^{F}_{jit_0}}{\sum_{j'} Invest_{j'it_0}} \qquad \forall i, j \tag{4.25}$$

with $\sum_j (sv^d{}_{ji} + sv^f{}_{ji}) = 1$, and μ_i is the scale parameter. To ensure the correct accounting, we also need the equalities:

$$KN_{it} = \sum_{t-1 \leq t' \leq t} \sum_{j=1}^{n} (\frac{1}{2} Invest^{D}{}_{j,i,t'} + \frac{1}{2} Invest^{F}{}_{j,i,t'})$$

$$\forall i, t > t_0. \tag{4.26}$$

The foreign exchange constraint can be written as follows.

$$TotX_t + F_t \geq TotM_t \qquad \forall t \tag{4.27}$$

where F_t stands for the foreign capital inflows including factor incomes from abroad.

We also impose bounds on F, X, and M as follows.

$$F_t \leq \overline{F}_t \cdot GDP_t \qquad \forall t \tag{4.28}$$

$$X_{it} \geq \underline{X_i} \cdot VA_{it} \qquad \forall i, t \tag{4.29}$$

$$M_{it} \leq \overline{M_i} \cdot VA_{it} \qquad \forall i, t \tag{4.30}$$

where $\overline{F_t}$, $\underline{X_i}$ and $\overline{M_i}$ are calibrated using base year data.

Finally, the following constraints ensure the origin-destination dynamics of the investments observed through the horizon.

$$\underline{Inv_t} \cdot sinv^{d}_{ij} \cdot (\sum_{i'} \sum_{j'} Invest_{i'j't}) \leq Invest^{D}_{ijt} \leq \overline{Inv_t} \cdot sinv^{d}_{ij} \cdot (\sum_{i'} \sum_{j'} Invest_{i'j't}) \quad \forall i, j, t \tag{4.31}$$

$$\underline{Inv_t} \cdot sinv^{f}_{ij} \cdot (\sum_{i'} \sum_{j'} Invest_{i'j't}) \leq Invest^{F}_{ijt} \leq \overline{Inv_t} \cdot sinv^{f}_{ij} \cdot (\sum_{i'} \sum_{j'} Invest_{i'j't}) \quad \forall i, j, t \tag{4.32}$$

where the coefficients, $sinv^{d}_{ij}$ and $sinv^{f}_{ij}$, to determine the intersectoral investment flows are computed from base year data as follows:

$$sinv^{d}_{ij} = \frac{Invest^{D}_{ijt_0}}{\sum_{i'j'} Invest_{i'j't_0}} \qquad \forall i, j \qquad (4.33)$$

$$sinv^{f}_{ij} = \frac{Invest^{F}_{ijt_0}}{\sum_{i'j'} Invest_{i'j't_0}} \qquad \forall i, j \qquad (4.34)$$

and $\underline{Inv_t}$ and $\overline{Inv_t}$ are the lower and upper bounds which define an interval that allows substitution of investment goods among sectors.

4.2 ENERGY MODULE

We have illustrated the general overview of the Turkish energy sector in Chapter 3. The energy data for the base year, including the assumptions and procedures explaining how it was rearranged, are summarized in Appendix C. This section presents the assumptions and modeling issues related to energy activities. It begins with the assumptions used in our model, then we will define the sets, variables and constraints of the model.

The energy module is based on some fundamental assumptions which are listed as follows.

- Solid fuels consist of coal, lignite and wood.
- Domestic production of natural gas is ignored.
- Coal power plants consume imported hard coal only.
- Petroleum products power plants consume imported petroleum products only.
- Hydroelectricity power plants are considered under two sub-categories, i.e., hydroelectricity power plants with dam and run of river power plants, since these two technologies have significantly different investment and operation costs.
- Lignite resources are divided into three sub-categories based on the region lignite is extracted from. The reason is that there exist significant variations on the calorific values and extraction costs among the lignites of different origins. The regions defined by Seyhan [54] is used in this categorization.

- It is assumed that every plant has an economic lifetime and the plants retire once they complete their lifetimes. Economic lifetimes for each plant type are given in B.12. Note that the initial installed capacity is depreciated according to historical data.

- Geothermal heat and solar heat are ignored.

- All energy related variables are defined in terms of a unit energy measure, ktoe.

Sectoral energy demands is the sum of electric (E) and nonelectric energy (NE) components with non-electric energy further divided into components of petroleum (P), natural gas (N) and solids (S). Sub-categories of these are defined by the following sets:

$setE$	Set of electricity generating technologies.
$setS$	Set of solid fuel types used for non-electric energy.
$setP$	Set of petroleum products used for non-electric energy.
$setN$	Set of gas resources used for non-electric energy.
$setNE$	Set of all energy resources used for non-electric energy.

We also defined the following three sets which will be clarified in the following paragraphs.

$setBOTH$	Set of fuels used for both generating electricity and non-electric energy.
$setL$	Set of lignite types.
$setFF$	Set of fossil fuels including wood.

The sets with explicitly defined elements can be seen below.

$$setE = \{HydroDam, HydroRiver, Imported\ Coal, Imported\ Petroleum\ Products, Lignite_1, Lignite_2, Lignite_3, Natural\ Gas, Nuclear, Wind, Solar, Geothermal\}.$$

$$setS = \{Domestic\ Coal, Imported\ Coal, Lignite, Wood\}.$$

$setP$	=	$\{Domestic\ Petroleum\ Products, Imported\ Petroleum\ Products\}$.
$setN$	=	$\{Natural\ Gas\}$.
$setNE$	=	$setS \cup setP \cup setN$.
$setBOTH$	=	$\{Imported\ Coal, Imported\ Petroleum\ Products, Lignite_1, Lignite_2, Lignite_3, Natural\ Gas\}$.
$setL$	=	$\{Lignite_1, Lignite_2, Lignite_3\}$.
$setFF$	=	$\{Imported\ Coal, Imported\ Petroleum\ Products, Lignite_1, Lignite_2, Lignite_3, Natural\ Gas, Domestic\ Coal, Domestic\ Petroleum\ Products, Wood\}$.

The index q denotes the categories for all energy resources where $q \in (setE \cup setS \cup setP \cup setN \cup setL)$.

The variables representing energy activities are:

dNE_{iqt}	Energy supplied for sector i in year t for non-electric use where $q \in setNE$.
dE_{qt}	Electricity generation from resource $q \in setE$ in year t.
$newE_{qt}$	Incremental (flow) electricity coming on line from resource $q \in setE$ in year t
dL_{qt}	Lignite of type $q \in setL$ supplied for non-electric use in year t.
$totP_{qt}$	Total supply of primary fossil fuel $q \in setFF$ in year t.

Aggregated energy inputs defined in the previous section, i.e., S_{it}, P_{it}, N_{it} and E_{it}, are expressed as the sum of corresponding energy activities in Equations 4.35-4.38 which establish supply and demand balance for each sector and period.

$$S_{it} = \sum_{q \in setS} dNE_{iqt} \qquad \forall i, t \tag{4.35}$$

$$P_{it} = \sum_{q \in setP} dNE_{iqt} \qquad \forall i, t \tag{4.36}$$

$$N_{it} = \sum_{q \in setN} dNE_{iqt} \qquad \forall i, t \tag{4.37}$$

$$\sum_{i=1}^{n} E_{it} = \sum_{q \in setE} dE_{qt} \qquad \forall t \tag{4.38}$$

Total demand of each primary fossil fuel, $totP_{qt} \in setFF$, i.e., sum of sectoral consumptions and consumption in power industry, is calculated through the following equations.

$$totP_{qt} = (conv_q \cdot dE_{qt} + dL_{qt}) \qquad \forall t, q \in setL \tag{4.39}$$

$$totP_{qt} = (conv_q \cdot dE_{qt} + \sum_{i=1}^{n} dNE_{iqt}) \qquad \forall t, q \in (setBOTH \backslash setL) \tag{4.40}$$

$$totP_{qt} = \sum_{i=1}^{n} dNE_{iqt} \qquad \forall t, q \in (setFF \backslash setBOTH) \tag{4.41}$$

where $conv_q$ is the electric to thermal conversion factor, i.e., amount of fuel q needed for generating one unit of electricity. The reader is referred to Appendix B.1 for the list of conversion factors. Note that, $totP_{qt}$, $q \in setL$, has been distinguished from the other resources being used for both electric and non-electric consumption, which will be clarified at the end of this section.

Equations 4.42 and 4.43 represent resource limits. Equation 4.42 ensures that the total production of domestic coal, domestic crude oil and lignites throughout the planning horizon are not more than the corresponding reserves. Equation 4.43, on the other hand, limits the electricity generation by renewable resources with the corresponding annual potentials.

$$\sum_{t=t_0}^{t=T} totP_{qt} \leq Reserve_q$$
$$q \in (setL \cup \{Domestic\ Coal,\ Domestic\ Petroleum\ Products\}) \tag{4.42}$$

$$dE_{qt} \leq Potential_q$$
$$\forall t,\ q \in \{HydroDam,\ HydroRiver,\ Wind,\ Solar,\ Geothermal\} \tag{4.43}$$

where $Reserve_q$ represents the proven reserves for depletable resource q and $Potential_q$ represents the annual potential for renewable resource q. Turkey's reserves of the depletable energy resources and potentials for the renewable resources can be seen in Table 3.1.

Continuity equations identify new and retiring generating units, where t_q denotes the economic lifetime of generating unit q. Note that, economic-lifetime of each technology was assumed to be equal in the former studies, [4], [11], [41], [42] and [45], instead of employing technology-specific economic lifetimes.

$$dE_{qt} = dE_{q,(t-1)} + newE_{qt} - dE_{q,(t-t_q)} \qquad \forall t > t_0, q \in setE \qquad (4.44)$$

Annual changes in supplies of primary energy resources are limited in order to avoid high fluctuations from year to year.

$$totP_{qt} \leq totUP_{qt} \cdot totP_{q,(t-1)} \qquad \forall t > t_0, q \in setFF \qquad (4.45)$$

$$totP_{qt} \geq totLOW_{qt} \cdot totP_{q,(t-1)} \qquad \forall t > t_0, q \in setFF \qquad (4.46)$$

where $totUP_{qt}$ and $totLOW_{qt}$ are the coefficients to set upper and lower bounds on the annual changes.

In addition to the limiting constraints presented above, we also set bounds on sectoral consumption of energy resources in the same manner.

$$dNE_{iqt} \leq secUP_{qt} \cdot dNE_{iq,t-1} \qquad \forall t > t_0, i, q \in (setS \cup setP) \qquad (4.47)$$

$$dNE_{iqt} \geq secLOW_{qt} \cdot dNE_{iq,t-1} \qquad \forall t > t_0, i, q \in (setS \cup setP) \qquad (4.48)$$

where $secUP_{qt}$ and $secLOW_{qt}$ denote coefficients of the upper an lower bounds on sectoral consumption of solid fuels and petroleum products. Note that above constraints are written only for solid fuels and petroleum products but not for the natural gas and electricity, since Equation 4.17 is sufficient to control annual flows of sectoral natural gas and electricity demands. For electricity, additional bounds exist on incremental capacities (flows) of electricity generation units as follows.

$$newE_{qt} \leq IncUP_{qt} \cdot dE_{q,t-1} \qquad \forall t > t_0, q \in setE \tag{4.49}$$

$$newE_{qt} \geq IncLOW_{qt} \cdot dE_{q,t-1} \qquad \forall t > t_0, q \in setE \tag{4.50}$$

The energy modules of one-sector and multi-sector models have the same structure to some extent, that is, the constraints written in the previous part of this section are either the same as the constraints in the one-sector model or they are straightforward extensions of those defined in the one-sector model (see Section E.5 for the energy module of the one-sector model). However, the extension is not that easy especially when calculating sectoral energy costs. In the rest of the section, the challenging issues will be clarified and resulting constraints will be given.

In the one-sector model, total energy cost is calculated by simply adding up all costs incurred from energy related activities (see Equations E.30 and E.31 in Appendix E). In the multi-sector model, on the other hand, average end-use prices for electricity and non-electric use of lignite need to be determined endogenously in the model in order to calculate the sectoral energy costs.

As pointed out at the outset, three types of lignites are defined based on their origin of extraction. Our data set contains origin attribute for the lignites burned in power plants. However, the only data we have for the sectoral use of lignites is the total lignite consumption in each sector with its composition not identified. Three sets of equations are then introduced to cope with this ambiguity, i.e., Equation 4.39, 4.51 and 4.52, where Equation 4.39 has already been given before. Average cost of lignite is determined through Equation 4.51 in which cost of total lignite production in a year is divided by the production volume in the given year.

$$p_{Lignite,t} = \frac{\sum_{q \in setL} cf_{q,t} \cdot totP_{qt}}{\sum_{q \in setL} totP_{qt}} \qquad \forall t \tag{4.51}$$

Equation 4.52, on the other hand, ensures the demand-supply balance for non-electric use of lignite, i.e., total lignite produced for non-electric use is equal to the sum of sectoral lignite consumptions. Note that the same problem also arises for electricity, however, the sum of sectoral electricity demands has already been balanced to the total electricity production in Equation 4.38.

$$\sum_{i=1}^{n} dNE_{i,Lignite,t} = \sum_{q \in setL} dL_{qt} \qquad \forall t \tag{4.52}$$

Similar to the case of lignite, there are many electricity generation alternatives with different fuel, operation and investment costs while the unique output, electricity, is transmitted into a single pool which makes it groundless and impossible to distinguish the actual source of electricity used in a sector. Then, in order to calculate the average cost of generating electricity ($p_{Elec,t}$); sum of electricity related costs (fuel, operation & maintenance and annualized investment costs), is divided by the total electricity generation, for each year:

$$p_{Elec,t} = coef_{T\&D} \cdot \frac{\sum_{q \in setBOTH} cf_{q,t} \cdot conv_q \cdot dE_{qt} + \sum_{q \in setE} (co_{q,t} + ci_{q,t}) \cdot dE_{qt}}{\sum_{q \in setE} dE_{qt}} \qquad \forall t \tag{4.53}$$

where $coef_{T\&D}$ is the coefficient which is defined to incorporate the transmission and distribution costs into the average electricity cost. $cf_{q,t}$, $co_{q,t}$ and $ci_{q,t}$ denote the unit cost of fuel, operation&maintenance and investment for the corresponding power plants in year t, respectively. The reader is referred to Appendix B for the calculation of electricity generation costs.

In order to obtain domestic and foreign components of sectoral energy costs, we first need to calculate the shares of foreign and domestic components in electricity generation cost, ω_t^F and ω_t^D, respectively.

$$\omega_t^F = coef_{T\&D} \cdot \frac{\sum_{q \in setBOTH} \tau_{qt}^{fuel} \cdot cf_{q,t} \cdot conv_q \cdot dE_{qt} + \sum_{q \in setE} \tau_{qt}^{inv} \cdot ci_{q,t} \cdot dE_{qt}}{p_{Elec,t} \cdot \sum_{q \in setE} dE_{qt}} \qquad \forall t \tag{4.54}$$

$$\omega_t^D = 1 - \omega_t^F \qquad \forall t \tag{4.55}$$

where τ_{qt}^{fuel} and τ_{qt}^{inv} denote the shares of foreign components in fuel and investment costs, respectively. The denominator in Equation 4.55 is the cost of electricity generated in year t. The first sum in the numerator denotes the foreign component of power plants' fuel costs while the second sum denotes the foreign component of investment costs in year t.

Finally, domestic (foreign) component of sectoral energy cost in sector i and year t, $EC_{i,t}^{D}$ ($EC_{i,t}^{F}$), is equal to the sum of domestic (foreign) component of sectoral electricity cost and the cost of domestic (imported) fuels consumed for non-electric energy in the given sector.

$$EC_{i,t}^{D} = \omega_t^{D} \cdot p_{Elec,t} \cdot E_{it} + \sum_{q \in setNE} (1 - \tau_{qt}^{fuel}) \cdot cf_{q,t} \cdot dNE_{iqt} \qquad \forall i,t \qquad (4.56)$$

$$EC_{i,t}^{F} = \omega_t^{F} \cdot p_{Elec,t} \cdot E_{it} + \sum_{q \in setNE} \tau_{qt}^{fuel} \cdot cf_{q,t} \cdot dNE_{iqt} \qquad \forall i,t \qquad (4.57)$$

Note that $cf_{Lignite,t}$ is assigned to $p_{Lignite,t}$ for all t.

4.3 ENVIRONMENT MODULE

Three of the GHGs (CO_2, N_2O and CH_4) are taken into consideration in our study. In this section, we will explain how sectoral emissions are calculated and give the consequent equations one by one. Note that the recent GHG emission inventory is reported and calculation of emission factors are described comprehensively in Appendix G.

The procedure to calculate sectoral GHG emissions can be summarized as follows:

- Calculation of sectoral GHG emissions arising due to non-electric use of energy.
- Calculation of GHG emissions arising in power plants.
- Calculation of total GHG emissions in each sector using the values obtained in the steps above.

CO_2 emissions mainly arise from the combustion of fossil fuels. CO_2 emissions caused by the use of non-electric energy in sector i and year t, $EmissionNE_{CO_2,i,t}$, are determined by the following equation.

$$\begin{aligned} EmissionNE_{CO_2,i,t} = & ef_{Coal,CO_2} \cdot (dNE_{i,DomCoal,t} + dNE_{i,ImpCoal,t}) + \\ & ef_{Lignite,CO_2} \cdot dNE_{i,Lignite,t} + \\ & ef_{PetProd,CO_2} \cdot (dNE_{i,DomPetProd,t} + dNE_{i,ImpPetProd,t}) + \\ & ef_{NaturalGas,CO_2} \cdot N_{i,t} \qquad \forall i,t \end{aligned} \tag{4.58}$$

where ef_{Coal,CO_2}, $ef_{Lignite,CO_2}$, $ef_{PetroleumProducts,CO_2}$ and $ef_{NaturalGas,CO_2}$ denote the emission factors for *Coal*, *Lignite*, *Petroleum Products* and *Natural Gas*, respectively.

CH_4 emissions arise due to combustion of plant and animal waste and as fugitive emissions from solid fuels. Then, Equation 4.59 assures that CH_4 emissions in sector i due to consumption of non-electric energy in year t, $EmissionNE_{CH_4,i,t}$, is the sum of CH_4 emissions caused by combustion of *Wood*, and emissions arose during the production phase of *Domestic Coal* and *Lignite* which are then consumed in sector i.

$$\begin{aligned} EmissionNE_{CH_4,i,t} = & ef_{Coal,CH_4} \cdot dNE_{i,DomesticCoal,t} + \\ & ef_{Lignite,CH_4} \cdot dNE_{i,Lignite,t} + \\ & ef_{Wood,CH_4} \cdot dNE_{i,Wood,t} \qquad \forall i,t \end{aligned} \tag{4.59}$$

where ef_{Coal,CH_4}, $ef_{Lignite,CH_4}$ and ef_{Wood,CH_4} are the emission factors of CH_4 for *Coal*, *Lignite* and *Wood*, respectively.

The equation to calculate the N_2O emissions caused by non-electric use of energy is given in Equation 4.60. Note that ef_{Coal,N_2O}, $ef_{Lignite,N_2O}$, $ef_{PetroleumProducts,N_2O}$, $ef_{NaturalGas,N_2O}$ and ef_{Wood,N_2O} are assumed to be equal as explained in Appendix G.

$$\begin{aligned} EmissionNE_{N_2O,i,t} = & ef_{Coal,N_2O} \cdot (dNE_{i,DomCoal,t} + dNE_{i,ImpCoal,t}) + \\ & ef_{Lignite,N_2O} \cdot dNE_{i,Lignite,t} + \\ & ef_{PetProd,N_2O} \cdot (dNE_{i,DomPetProd,t} + dNE_{i,ImpPetProd,t}) + \\ & ef_{Wood,N_2O} \cdot dNE_{i,Wood,t} \\ & ef_{NaturalGas,N_2O} \cdot N_{i,t} \qquad \forall i,t \end{aligned} \tag{4.60}$$

Equation 4.61 calculates the total emissions arising due to electricity generation, $EmissionElec_t$.

$$
\begin{aligned}
&EmissionElec_t = \\
&ef_{Coal,CO_2} \cdot conv_{ImpCoal} \cdot dE_{ImpCoal,t} + ef_{Lign,CO_2} \cdot \sum_{q \in setL} conv_q \cdot dE_{q,t} + \\
&ef_{PetProd,CO_2} \cdot conv_{ImpPetProd} \cdot dE_{ImpPetProd,t} + ef_{NGas,CO_2} \cdot conv_{NGas} \cdot dE_{NGas,t} \\
&ef_{Coal,N_2O} \cdot conv_{ImpCoal} \cdot dE_{ImpCoal,t} + ef_{Lign,N_2O} \cdot \sum_{q \in setL} conv_q \cdot dE_{q,t} + \\
&ef_{PetProd,N_2O} \cdot conv_{ImpPetProd} \cdot dE_{ImpPetProd,t} + ef_{NGas,N_2O} \cdot conv_{NGas} \cdot dE_{NGas,t} \\
&ef_{Lignite,CH_4} \cdot \sum_{q \in setL} conv_q \cdot dE_{q,t} \qquad \forall i, t
\end{aligned}
\tag{4.61}
$$

Finally, total emission in sector i and year t, $totEmission_{i,t}$, is defined as the sum of CO_2, N_2O and CH_4 emissions in the given sector, and the emission coming from the sectoral consumption of electricity. Note that the total emissions caused by generating electricity is distributed among sectors proportional to sectoral electricity consumptions.

$$
\begin{aligned}
totEmission_{i,t} = &Emission_{CO_2,i,t} + Emission_{CH_4,i,t} + Emission_{N_2O,i,t} + \\
&EmissionElec_t \cdot \frac{E_{it}}{\sum_{j=1}^{n} E_{jt}} \qquad \forall i, t
\end{aligned}
\tag{4.62}
$$

CHAPTER 5

RESULTS AND ANALYSIS

The model is coded for the GAMS optimization platform and solved by the nonlinear programming algorithm CONOPT with 2003 as the base year. There are two main reasons for selecting 2003 as the base year. First, the recent input-output table, which discloses the intersectoral structure of the economy, was published for the year 2002. However, Turkey suffered a financial crisis in 2001 resulting in significant distortions on macroeconomic and energy balances of the country. Then, 2003 is assumed to be close enough to keep the structure of I-O tables of 2002 while being free from the distortions of the 2001 crisis to some extent. The planning horizon extends to 2030 but the model is solved for the period 2003-2040 in order to reduce the end of horizon effects.

To provide a fluent and compact presentation of our analysis, it is preferred that the details related to data sets and parameters be given in the appendices. As explained in the previous chapter, our model comprises three modules, which are macroeconomic, energy and environment modules, and each module has its own data set and parameters. The data used in our model are heterogeneous in sources, dates, units, and sectoral detail. Thus for providing consistency, it requires a significant effort to preprocess the data sets according to the model requirements and to set the values of the parameters. Moreover, some preliminary information would be required to understand the whole picture. The reader is referred to the following appendices for the base year data, model parameters and preliminary calculations.

- Appendix B: Energy Data and Preliminary Calculations

- Appendix C: Macroeconomic Data and Preliminary Calculations

- Appendix D: Model Calibration and Parameters
- Appendix G: Environmental Data and Preliminary Calculations

The chapter begins with a detailed description of the scenarios. Then, a comprehensive analysis for the Base Case scenario is presented in Section 5.2. Sections 5.3 and 5.4 are devoted to reveal the impacts of a nuclear power programme and a single economy-wide quota on GHG emissions, respectively. Carbon Capture and Storage (CCS) technology is introduced in Section 5.5 including the analysis of implementing power plants coupled with CCS technology. Finally, setting quotas on sectoral GHG emissions is discussed in Section 5.6 and effects of changes in world energy prices are investigated in Section 5.7.

5.1 SCENARIOS

Our model can be used to evaluate a range of policy options referring to fuel substitution and domestic resource use, emission scenarios and abatement alternatives as well as the sectoral implications of these policies. In this framework, a number of scenarios were defined under four main categories as seen in Table 5.1.

5.1.1 NO-ABATEMENT SCENARIOS

Scenarios that leave out any consideration of environmental policies (a base-case, an open and a no-nuclear scenario) are defined first. The Base Case Scenario (BC) represents current plans of the Government without any explicit consideration of emission-abatement policies. In parallel with Government intention, the BC scenario anticipates the adoption of three nuclear plants in 2020, 2022 and 2025 each with a capacity of 4800 MW and therefore is the most likely scenario to unfold in keeping with feasibility considerations.

Although recent declarations and actions imply that the Government is very decisive on building nuclear plants as soon as possible, a national consensus has not been yet reached since many people, especially non-governmental environmental organizations, are against nuclear power due to the accompanying risks. Furthermore the economic feasibility of nuclear plants

Table 5.1: Scenarios.

No-abatement scenarios	base case scenario (BC)	reflects current government plans that include three nuclear projects each amounting to 4800 MW
	no-nuclear scenario (NoN)	BC without any nuclear generation
	open scenario (OP)	BC with the scope of the nuclear programme decided by the model
Abatement scenarios: General	BCq20, BCq30, BCq40	BC with 20%, 30%, 40% reductions in cumulative BC emissions until 2030 achieved through fuel substitution
	NoNq20, NoNq30, NoNq40	NoN with 20%, 30%, 40% reductions in cumulative BC emissions until 2030 achieved through fuel substitution
	OPq20, OPq30, OPq40	OP with 20%, 30%, 40% reductions in cumulative BC emissions until 2030 achieved through fuel substitution
	BCccsQ20, BCccsQ30, BCccsQ40	20%, 30%, 40% reductions in cumulative BC emissions until 2030 achieved through fuel substitution and carbon-capture-and-storage
Abatement scenarios: Sectoral	Aq30	BC with 30%, reduction in cumulative BC emissions in *Agriculture* until 2030 achieved through fuel substitution
	IEq30	BC with 30%, reduction in cumulative BC emissions in *Industry: Energy-intensive* until 2030 achieved through fuel substitution
	IOq30	BC with 30%, reduction in cumulative BC emissions in *Industry: Other* until 2030 achieved through fuel substitution
	Sq30	BC with 30%, reduction in cumulative BC emissions in *Services* until 2030 achieved through fuel substitution
	Tq30	BC with 30%, reduction in cumulative BC emissions in *Transportation* until 2030 achieved through fuel substitution
Price scenarios	BC-low	BC with low world energy prices
	BC-high	BC with high world energy prices

are also open to question. Then, the No-Nuclear Scenario (NoN), which assumes that no nuclear power programme will be executed in the planning horizon, is defined where all other assumptions are the same as BC. Comparisons between the solutions of BC and NoN scenarios will be used to assess the impacts of a nuclear power programme on energy, environmental and macroeconomic variables.

Finally, the Open scenario (OP), is defined to understand what happens if the scope of the nuclear power programme is determined in the model within reasonable capacity limits. That is, the model is allowed to utilize nuclear plants after 2020 but restricted by capacity limits (the capacities in BC are given as upper bounds).

5.1.2 ABATEMENT SCENARIOS: GENERAL

The scenarios in this group include the abatement policies directed towards the overall economy without addressing a specific sector, and two types of such abatement policies are taken into consideration in our study.

- The scenarios obtained by defining emission quotas by simply adding constraints which ensure a certain amount of reduction in total cumulative GHG emissions.
- The scenarios in which the power plants coupled with CCS technology are available.

Abatement objectives are achieved through fuel substitution in the first group of scenarios. Then, the solutions of these scenarios clearly demonstrate how the economy moves from high-emission energy resources to low-emission resources and concomitant implications of this shift. These scenarios also form a basis for analyzing how each sector is influenced as well as the overall economy when similar targets become obligatory in near future due to the Kyoto Protocol recently signed by Turkey.

These scenarios are modeled by appending the following constraint to the corresponding original model (BC, NoN or OP).

$$CumEmis = \sum_{t=t_0}^{2030}[\sum_{i=1}^{n}(EmissionNE_{CO_2,i,t} + EmissionNE_{CH_4,i,t} + EmissionNE_{N_2O,i,t}) + EmissionElec_t] \tag{5.1}$$

$$CumEmis \leq qouta \cdot CumEmis^{BC} \tag{5.2}$$

where total cumulative emission between 2003-2030, *CumEmis*, is calculated in Equation 5.1 and is restricted with a certain proportion, *quota*, of the cumulative base case emissions, $CumEmis^{BC}$, in Equation 5.2. Three levels of *quota*, i.e., 60%, 70% and 80%, which correspond to 40%, 30% and 20% reductions in cumulative GHG emissions of the BC scenario, are employed in our computations.

In the general abatement scenarios of the second group, the impacts of implementing CCS integrated power plants will be investigated as well as fuel substitution. Note that power plants coupled with CCS technology emit very low amounts of CO_2 but require higher investment compared to the conventional plants of the same type. The mere revision made for embedding CCS integrated power plants into our model is the redefinition of *setE*, set of electricity generation technologies, as follows:

$$
\begin{aligned}
setE \;=\; & \{HydroDam,\ HydroRiver,\ Imported\ Coal,\ Imported\ Petroleum\ Products, \\
& Lignite_1, Lignite_2, Lignite_3, Natural\ Gas, Nuclear, Wind, Solar, Geothermal, \\
& Imported\ Coal - CCS,\ Lignite_1 - CCS,\ Lignite_2 - CCS,\ Lignite_3 - CCS, \\
& Natural\ Gas - CCS\}.
\end{aligned}
$$

where $Imported\ Coal - CCS$, $Lignite_1 - CCS$, $Lignite_2 - CCS$, $Lignite_3 - CCS$, $Natural\ Gas - CCS$ denote the associated power plants integrated with CCS technology. Note that CCS technology is only integrated with fossil fuel-fired power plants, such as coal, lignite and natural gas plants since other electricity generating options are assumed to emit no emission in our model. However, in spite of being a fossil fuel-fired power plant, petroleum products plants are ignored since our BC results showed that petroleum plants were utilized at minimum by the model even with current cost figures.

The aim of defining a policy including CCS integrated power plants is to investigate whether it is advantageous to implement these plants or under which circumstances these plants would be utilized. We also try to analyze the implications once these plants are implemented.

5.1.3 ABATEMENT SCENARIOS: SECTORAL

In a similar way as quotas were set on total cumulative GHG emissions; the scenarios, in which sectoral GHG emissions are restricted individually, are defined. That is, the model is run five times with sectoral GHG emissions of only one sector being restricted in each run. Note that the assumptions in these scenarios, other than the constraints on sectoral emissions, are the same as the BC scenario.

The models for this group of scenarios are obtained by appending following equations to the

BC model:

$$SecCumEmis_i = \sum_{t=t_0}^{2030} totEmission_{i,t} \qquad \forall i \qquad (5.3)$$

$$SecCumEmis_i \leq qouta_i \cdot SecCumEmis_i^{BC} \qquad \forall i \qquad (5.4)$$

where $SecCumEmis_i$ denotes the cumulative sectoral emissions arose in sector i and $SecCum-Emis_i^{BC}$ stands for the corresponding sectoral emission obtained under BC scenario. Note that, when setting a quota on a specific sector, the emissions of the other sectors are forced so as not to exceed their base case levels. That is, $quota_i = 1, \forall i | i = i'$ where i' is the sector under consideration.

5.1.4 PRICE SCENARIOS

Two scenarios, BC-high and BC-low, are defined in order to investigate the influence of the changes in world energy prices. Both scenarios are inspired from those introduced by IEA in World Energy Outlook (WEO) 2010 [55]. We have used the price projections in the ”New Policies Scenario”, the reference scenario in World Energy Outlook 2010, for all no-abatement and abatement scenarios. The projections of the other two scenarios given in [55], ”Current Policies Scenario” and ”450 scenario”, are used in our BC-low and BC-high scenarios, respectively. Note that the term ”current” in the ”Current Policies Scenario” has been left by the former volumes of World Energy Outlook which does not include the recent long-term commitments of the governments. The ”New Policies Scenario” is built based on the recent measures, governments has already taken and ”450 Scenario” assumes an energy pathway which provides keeping the increase in global temperature by 2 degrees Celsius.

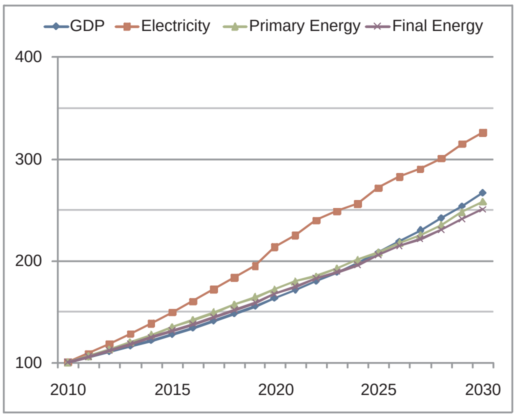
5.2 BASE CASE SCENARIO (BC)

Before going further into analysis phase, it would be better to give a brief information about technical details of the model. As explained at the outset, the model is coded for the GAMS optimization platform and solved by the nonlinear programming algorithm CONOPT. It includes 14,649 variables and 20,515 equations and it takes several hours for GAMS to find the optimal solution without guaranteeing whether it is a global optimum. Then, the model was run for several sets of initial points to attain a better local optimal solution. Note that the statistics above are given for the BC scenario but the models for other scenarios have almost the same figures. For example, the model including power plants coupled with CCS technology includes 20,700 variables and 15,024 equations.

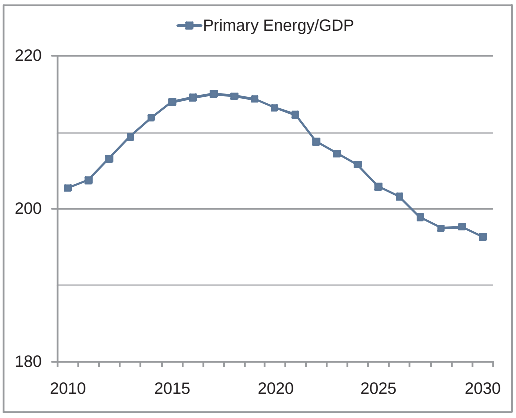
In our model, GDP and all other macroeconomic variables including the sectoral decomposition of total labor, as well as all energy variables are determined endogenously through utility maximization. Table 5.2 and Figure 5.1(a) show a selection from the main macroeconomic and energy indicators computed for the BC scenario. They point out on the average a 5% annual growth rate for GDP and for the primary and final energy demands, and a 6% growth rate for electricity consumption. These figures are slightly under short-term Government forecasts, [47] and [56], but are closer to longer term historical trends. Table 5.2 also shows the gap between imports and exports. As expressed in the foreign trade constraint 4.27, imports are restricted so as not to exceed the sum of exports and foreign capital inflows F_t. The results show that F_t is always computed at its upper bound as defined in constraint 4.28 which restricts it to a certain proportion of the GDP. This observation together with the increasing cost of imported energy, reveal Turkey's dependence on energy and foreign capital inflows in order to sustain its growth. The model has been calibrated so as to agree with the general trend of the Turkish economy and the trajectories computed for the base case are not out of line with mainstream expectations. The model would have to be recalibrated however, if Turkey were to achieve a higher savings rate in the future to moderate its dependence on foreign capital.

Table 5.2: Main Indicators: BC.

		2010	2015	2020	2025	2030
GDP	2003 prices, Billions TL	596.6	759.1	969.2	1239.6	1592.2
	Avg. Growth	4.5%	4.9%	5.0%	5.0%	5.1%
Imports, M	2003 prices, Billions TL	185.5	255.8	336.5	428.4	540.1
	% of GDP	31.1%	33.7%	34.7%	34.6%	33.9%
Exports, X	2003 prices, Billions TL	149.7	210.3	278.4	354.1	444.5
	% of GDP	25.1%	27.7%	28.7%	28.6%	27.9%
Foreign Energy Cost, EC^F	2003 prices, Billions TL	52.0	79.9	109.1	138.1	172.3
	% of GDP	8.7%	10.5%	11.3%	11.1%	10.8%
Electricity	TWh	240.7	358.3	514.2	654.1	784.2
	Avg. Growth	7.6%	8.3%	7.5%	4.9%	3.7%
Primary Energy	Mtoe	121.0	162.4	206.7	251.6	312.6
	Avg. Growth	6.1%	6.1%	4.9%	4.0%	4.4%
Final Energy	Mtoe	93.8	123.0	156.1	192.7	234.5
	Avg. Growth	5.7%	5.6%	4.9%	4.3%	4.0%



(a) Development of Key Indicators.



(b) Energy Intensity, toe/1000 TL.

Figure 5.1: Energy and Macroeconomic Indicators: BC.

Energy efficiency, as measured by energy consumed per thousand Turkish lira of GDP, is graphed in Figure 5.1(b). It displays a slight incline until 2015 followed by a decreasing trend due to the increasing technical progress (see the explanation for γ parameters in Appendix D.1).

Figure 5.2 shows the development of sectoral shares of the GDP. It indicates no major changes in the current structure of the economy, except a slow decline in agriculture and a slow increase in industry that are consistent with official forecasts.

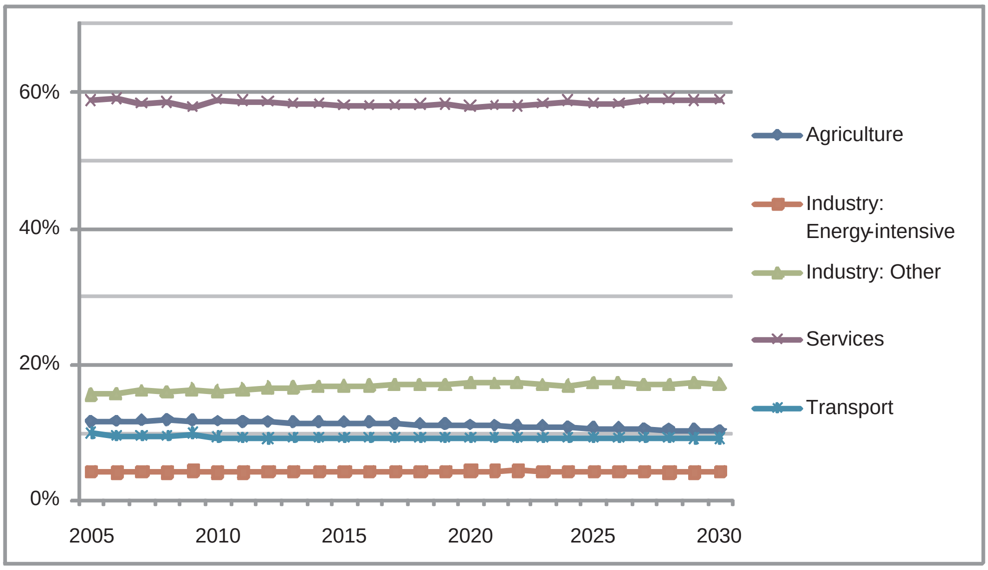
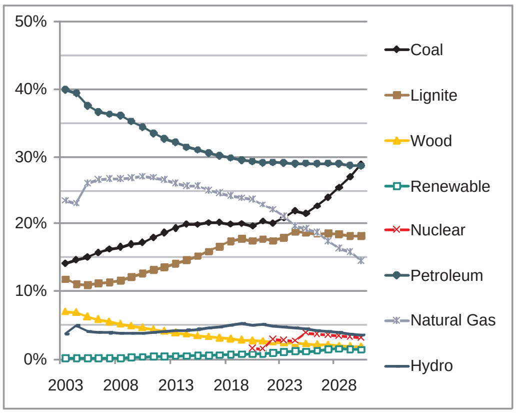
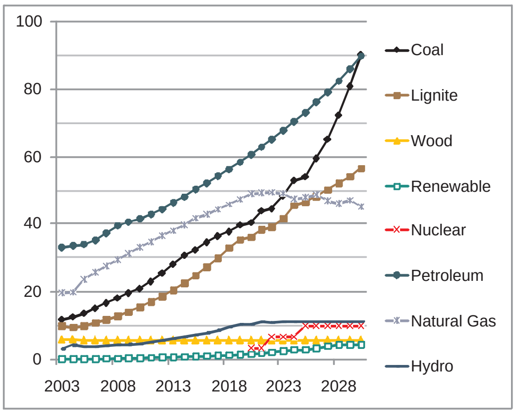


Figure 5.2: Development of Sectoral Shares of the GDP: BC.

Figures 5.3(a) and 5.3(b) show the primary energy composition by fuel types through the



(a) Percentages of the Total Supply



(b) Mtoe.

Figure 5.3: Primary Energy Supply: BC.

planning horizon as percentages of the total supply and in actual amounts, respectively. Figure 5.4, on the other hand, displays the total primary energy supply. Following remarks are noteworthy:

- The share of natural gas and petroleum products gradually decreases due to increasing oil and gas prices.
- Significant increase is observed in consumptions of high-emission fossil fuels, lignite and coal. Both resources approximately double their initial shares at the end of the planning horizon.
- At the end of the planning horizon, nuclear energy accounts for more than 3% of the total supply and renewable energy, consisting of wind, solar and geothermal electricity, nearly 1.5%.

Figures 5.5(a), 5.5(b), 5.6(a) and 5.6(b) illustrate the shares of the electricity generating options, actual generation amounts by each technology, gross generation and average cost of generating electricity, respectively. The break-down of renewable resources by technology, i.e., geothermal, solar and wind, can be seen in Figure 5.7. Immediate observations regarding these figures are as follows.

- Gross generation of electricity exceeds 800 TWh at the end of the planning horizon.

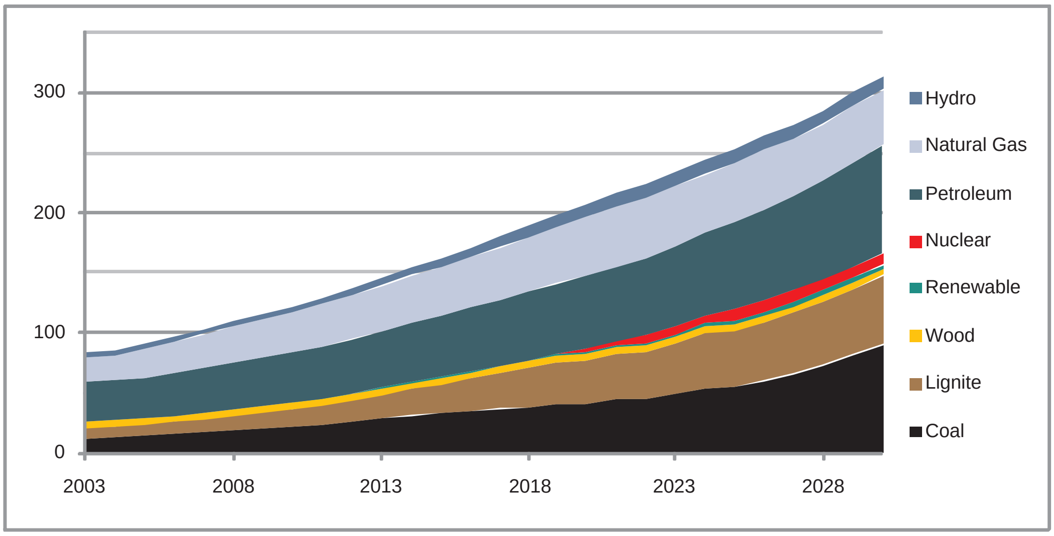
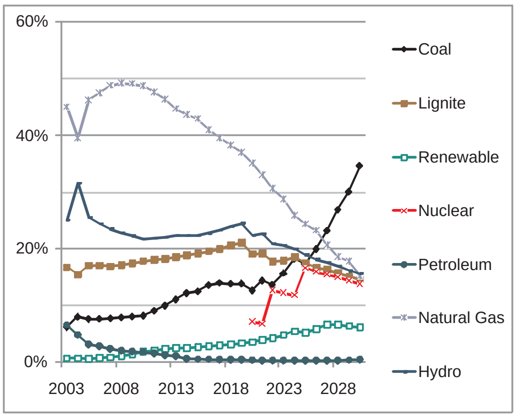


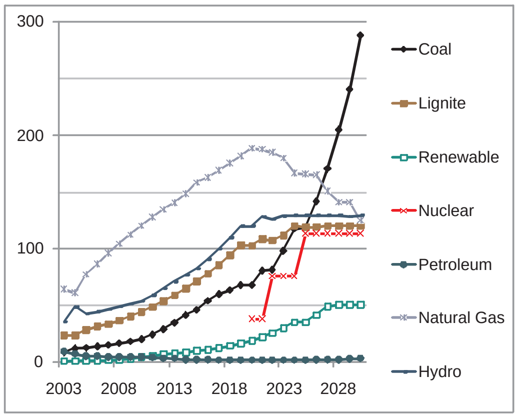
Figure 5.4: Total Primary Energy Supply: BC, Mtoe.

- The share of natural gas decreases to 35% by 2020 and to 15% by 2030.
- At the end of the planning horizon, nuclear power accounts for nearly 15% of the total supply.
- Renewable energy accounts for more than 6% of the gross generation by 2030.
- Although hydroelectric generation after 2020 is three times as much as it was in 2005, its share gradually decreases as resources are used to the full.
- Solar power plants with extremely high cost of generating electricity are not utilized during the planning horizon.
- Average cost of generating electricity increases in the first years of the horizon due to increasing cost of energy as well as increasing share of natural gas power plants. The average cost peaks in 2008 when a sharp increase has been observed in world energy prices.

Figures 5.8(a) and 5.8(b) display the comparison of BC results and government projections in terms of gross generation and primary energy supply, respectively. As seen in Figure 5.8(a), electricity generation in BC scenario is almost the same with the government projections. Primary energy supply in BC scenario, on the other hand, is lower compared to government projections as seen in Figure 5.8(b). The difference between projections for primary energy supply is, to some extent, due to the assumption of no geothermal or solar heat in our model.

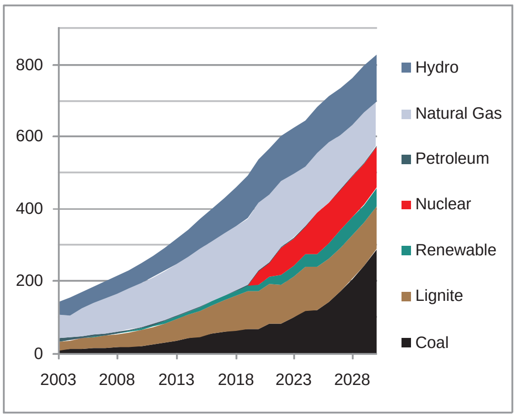


(a) Percentages of Gross Generation.

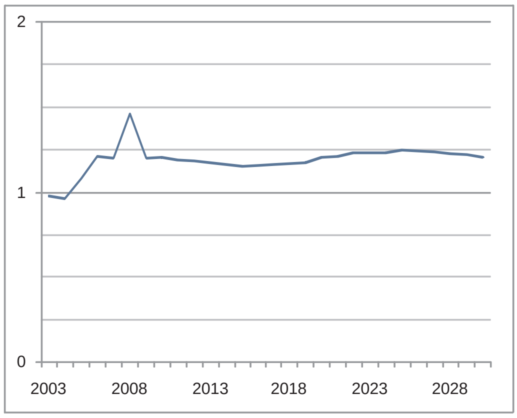


(b) TWh.

Figure 5.5: Electricity Generation: BC.



(a) Gross Generation: TWh.



(b) Average Cost of Generating Electricity, MTL/ktoe.

Figure 5.6: Gross Generation and Average Cost of Generating Electricity: BC.

Figures 5.9(a) and 5.9(b) show the composition of primary energy supply for government and BC projections, respectively. As seen in these figures, although the resulting shares in 2020 are quite close in both sets of projections, higher use of coal and lignite and lower use of natural gas have been observed until 2020 in BC scenario.

Break-down of sectoral final energy consumptions by main energy inputs, sectoral value-addeds and GHG emissions are presented in Table 5.3 which will be used as a benchmark data-set in the following sections. Besides, Tables 5.7, 5.8 and 5.9 (at the end of the chapter) summarize the computational results (main indicators, break down of primary energy and electricity by resource type) of the scenarios analyzed in the following sections. Finally, Appendix H presents detailed results for each scenario. In Appendix H, the reader can also

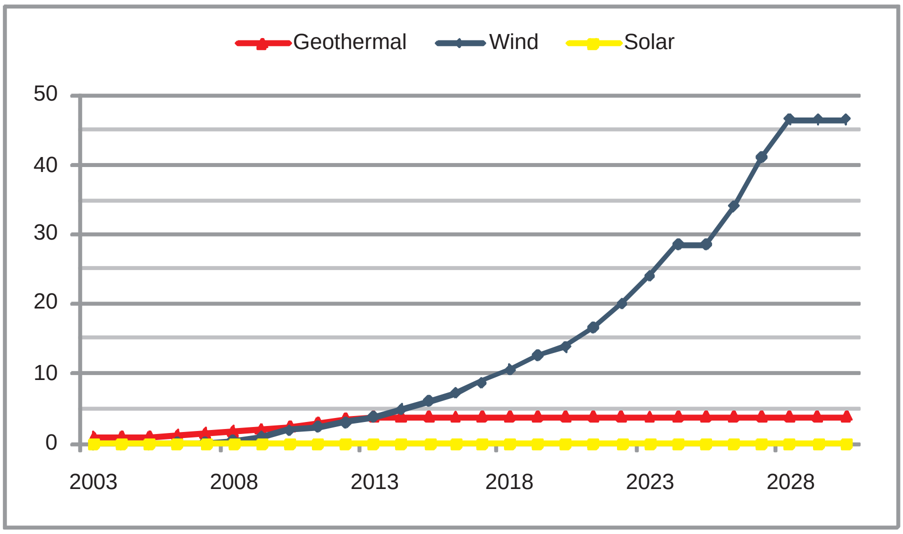
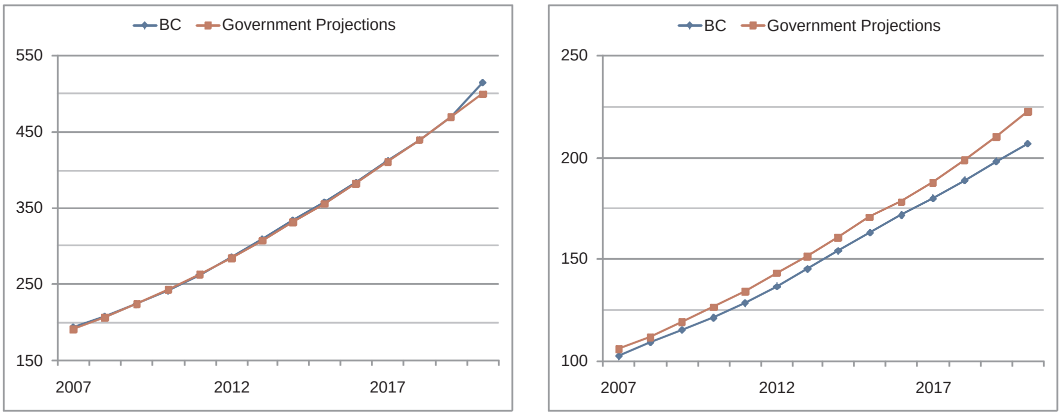


Figure 5.7: Electricity Generated by Renewable Resources: TWh, BC.

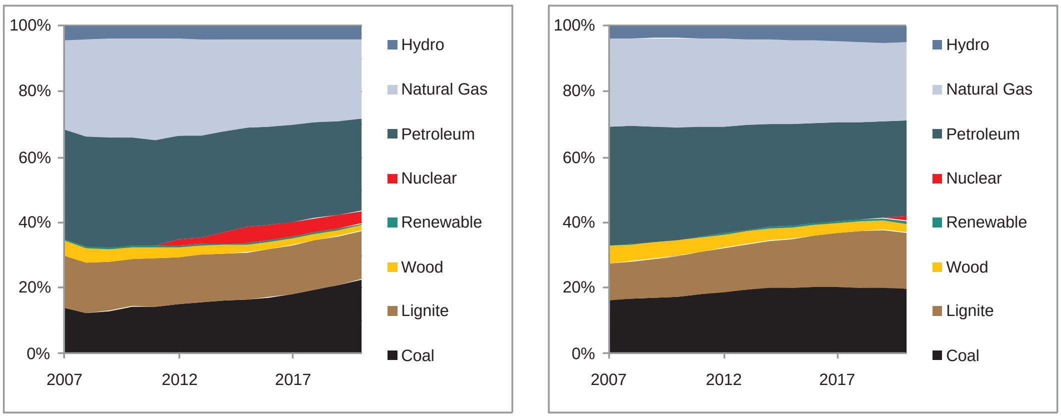


(a) Electricity: TWh.

(b) Primary Energy Supply: Mtoe.

Figure 5.8: BC vs Government Projections.

find the comparison of the main scenarios in terms of their dependency on the foreign energy.



(a) Government Projections.

(b) BC.

Figure 5.9: Primary Energy Supply: BC vs Government Projections.

Table 5.3: Sectoral Energy and Macroeconomic Indicators: BC.

	Electricity Mtoe	Natural Gas Mtoe	Petroleum Products Mtoe	Solid Fuels Mtoe	Value-Added Billions TL	GHG Emission Million tons
Agriculture						
2010	0.82	0.00	4.15	0.00	65.24	17.29
2020	2.02	0.00	6.19	0.00	99.81	29.65
2030	3.12	0.00	9.29	0.00	151.36	46.30
Industry: Energy-intensive						
2010	2.89	1.51	4.77	4.71	23.53	53.19
2020	6.64	2.19	6.60	7.91	40.03	92.10
2030	9.46	3.01	8.84	11.11	62.29	132.90
Industry: Other						
2010	6.73	4.93	7.82	9.62	89.71	111.77
2020	14.58	7.19	11.01	16.81	154.93	197.33
2030	22.46	10.40	15.65	26.00	255.19	310.97
Services						
2010	10.08	5.56	3.65	10.13	328.91	101.38
2020	20.54	7.23	4.66	16.19	523.20	184.47
2030	31.69	10.74	6.85	25.67	878.72	309.80
Transportation						
2010	0.18	0.01	16.24	0.00	52.46	50.67
2020	0.43	0.01	25.90	0.00	82.94	81.48
2030	0.71	0.02	39.51	0.00	135.61	124.86
Entire Economy						
2010	20.70	12.00	36.64	24.46	559.85	334.31
2020	44.22	16.62	54.36	40.90	900.91	585.02
2030	67.44	24.17	80.13	62.78	1483.17	924.84

5.3 A NUCLEAR POWER PROGRAMME

Two types of comparison will be performed in this section:

- BC vs OP to answer the following questions:

  What are the implications of implementing the nuclear programme under consideration on the energy balance of Turkey?

  What are the economic implications of implementing the nuclear programme under consideration?

  What is the level of reduction in GHG emissions owing to implementation of the nuclear programme?

- BC vs OP to answer the following question:

  What percent of the projected nuclear capacity would be installed if the scope of the programme were determined by the model?

Before continuing with the details of the analysis, it should be noted that ”Stacked column graphs” are used in the rest of this chapter, in order to reveal the mechanisms of substitution dynamics. These graphs display the deviation of a scenario from a base scenario in actual amounts or as percentages of the base case levels. For example, when comparing the results of Scenario A to those of Scenario B (which will be represented as [A-B] in the figure captions); the solution values of the variables in Scenario B are subtracted from the corresponding values obtained under Scenario A. A positive value in these figures indicates that the variable has a greater solution value in Scenario A compared to Scenario B. Similarly, a negative value is the indication of a decrease. Such a representation is quite descriptive in understanding how substitution takes place among energy resources since it includes the following information:

- The energy resources of which supply/consumption amounts decreased and the level of the decrease

- The energy resources of which supply/consumption amounts increased and the level of the increase

We employ this representation not only in the analysis of energy variables, but also in the analysis of macroeconomic and environmental variables such as GDP, energy costs and GHG emissions when comparing the scenarios with respect to macroeconomic and environmental aspects.

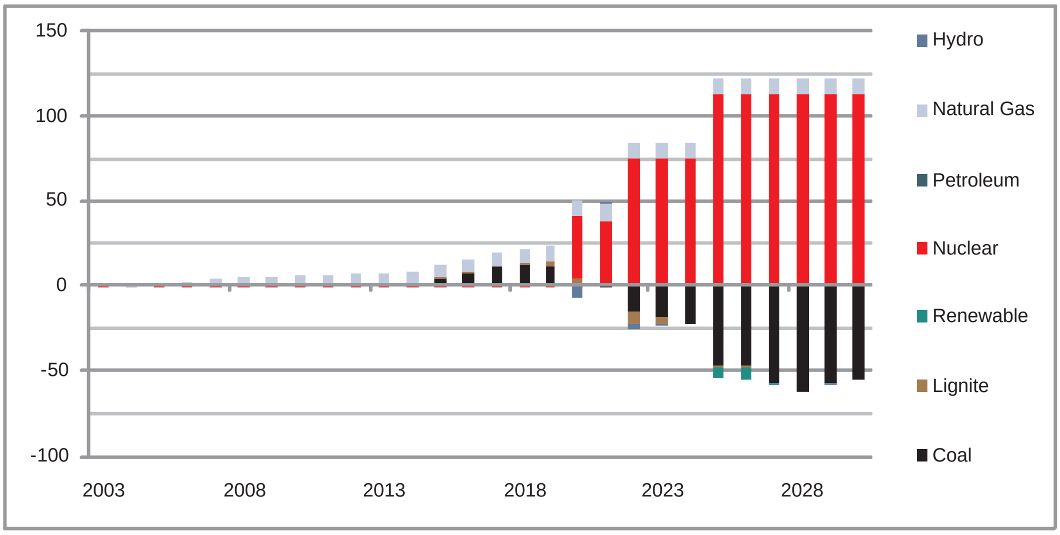


Figure 5.10: Electricity Generation: [BC-NoN], TWh.

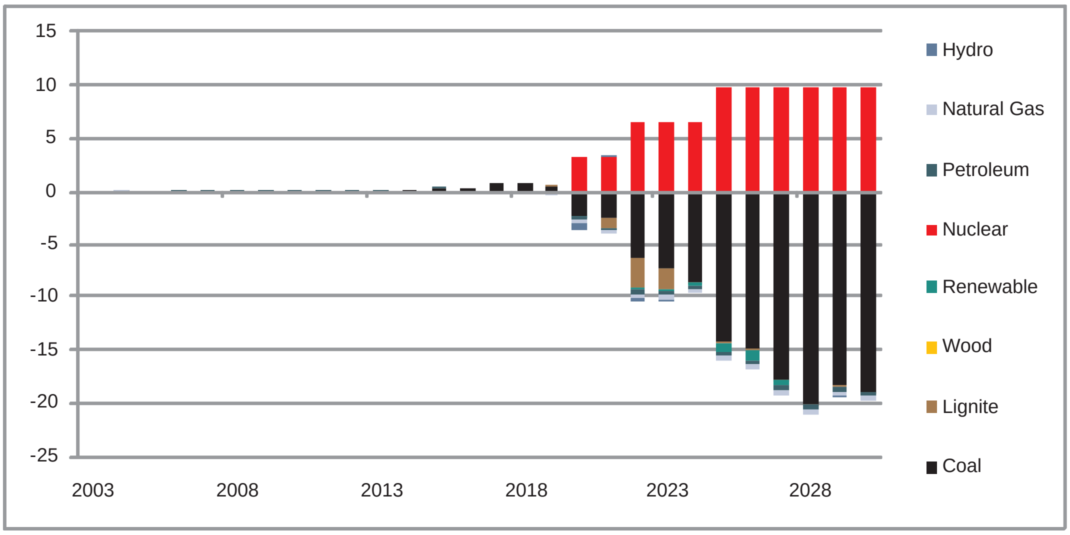


Figure 5.11: Primary Energy Supply: [BC-NoN], MToe.

Figures 5.10, 5.11 and 5.12 illustrate the comparison of BC and NoN in terms of electricity generation, primary energy supply and final energy consumption, respectively. These figures together imply that nuclear power plants mainly replace coal plants and result in a decrease in primary coal supply, accordingly. Following remarks will be helpful in understanding what

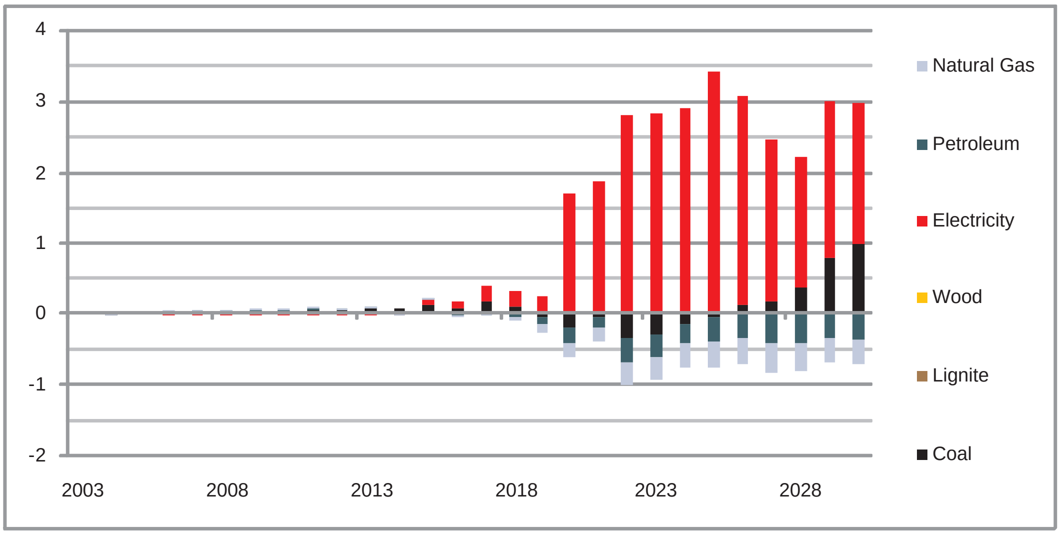


Figure 5.12: Final Energy Demand: [BC-NoN], MToe.

happens once the aforementioned nuclear programme is implemented.

- As seen in Figure 5.10, there is a gradual increase in natural gas plants until 2020 in which the first nuclear plant is commissioned. The reason of this increase is to maintain feasibility, considering the Equations 4.44 and 4.50, when a sudden increase in total electricity supply occurs in the given year (2020).

- Natural gas is selected for expansion of power capacity until 2015 and is accompanied with lignite and coal between 2015-2020. The reason is that, coal and lignite plants mostly hit their capacity upper bounds in the first years of the horizon while natural gas is at its lower bound throughout the planning horizon.

- Note that the increase in natural gas in Figure 5.10 keeps on existing after 2020 which is due to the assumption that a newly added capacity exists for a duration of its economic lifetime which is 25 years for the natural gas plants.

- No change in primary supply of natural gas, see Figure 5.11, indicates that the increasing consumption of natural gas in power industry (Figure 5.10) is totally shifted from non-electric consumption of natural gas (Figure 5.12).

- Decrease in coal consumption in power plants opens a room for non-electric use of coal, which explains the marginal increase of coal in Figure 5.12.

Figure 5.13 summarizes the comparison between BC and NoN with respect to main indicators. Note that the calculations in this figure are made based on cumulative amounts (sum of amounts through 2003-2030) for each variable. As seen in this figure, the nuclear power programme results in a marginal increase in GDP although the energy costs increase by 1.3%. Moreover, it is observed that the rise in the energy costs is balanced with the the growth of the economy due to higher use of final energy (mainly resulting from increased electricity supply).

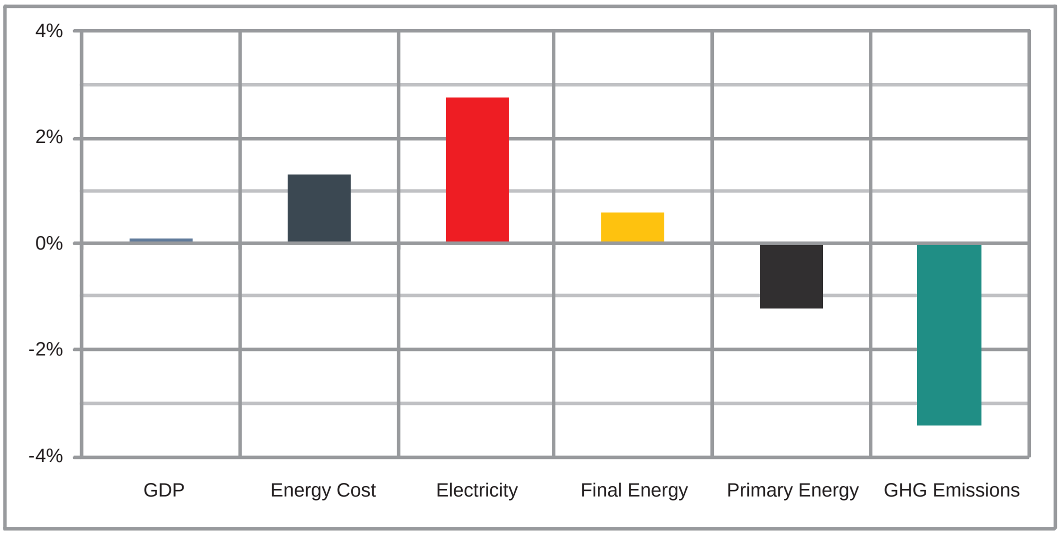


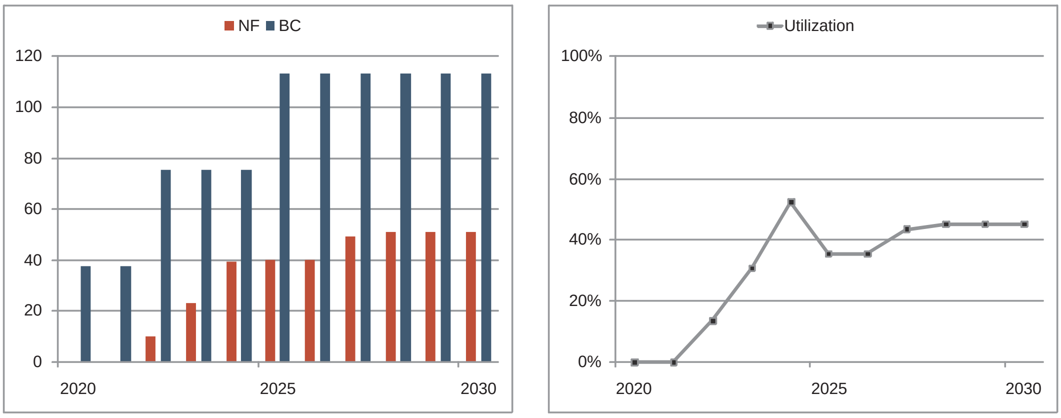
Figure 5.13: Change in Main Indicators: [BC-NoN], Percentages of the BC Levels.

Following observations are also remarkable:

- Cumulative primary energy supply decreases by 1.2% when the nuclear programme is implemented. This difference is mainly due to the replacement of less efficient coal plants by the nuclear plants. That is, the amount of primary energy used by a coal power plant is 2.38 times as much as the energy it generates. Electricity generated by nuclear power plants, on the other hand, is assumed to be primary resource as it is the case for renewable resources.

- Implementation of the nuclear programme grants a 3.5% decrease in cumulative GHG emissions. This result is again due to the shift from coal plants to cleaner nuclear plants.

- Implementing the power programme results in a 2.8% increase in total electricity generation as well as a 0.6% increase in final energy demand accompanied with a 1.3%



(a) TWh. (b) Utilization: Percentages of the BC Capacities.

Figure 5.14: Nuclear Electricity: BC vs OP.

increase in total energy costs in return.

Figure 5.14(a) illustrates the nuclear electricity generated under BC and OP scenarios. Figure 5.14(b), on the other hand, shows what percent of the nuclear capacity would be implemented if the capacity constraints of the nuclear variables were relaxed instead of forcing the model to build fixed capacities. These figures make it clear that building smaller nuclear plants instead of 4.8 GW plants in the current programme or a single ~5 GW plant commissioned around 2025, would be sufficient to benefit from the nuclear power.

5.4 QUOTAS SET ON TOTAL GHG EMISSIONS

The aim of this section is to reveal the impacts of an economy-wide quota set on cumulative GHG emissions. As explained in Table 5.1, we run our model under three levels of quotas: 60%, 70% and 80%, which are set on BC emissions. Results pertaining to each level of quota and for each setting (BC, NoN and OP) are tabulated in Appendix H.1. However in this section, a set of illustrative results (including only the analysis for the 30% reduction in GHG emissions) is presented. Following comparisons will be performed at the outset:

- BC vs BCq30 to analyze the impacts of a 30% emission quota under a nuclear programme.

- NoN vs NoNq30 to analyze the impacts of a 30% emission quota without a nuclear programme.

- OP vs OPq30 to analyze the impacts of a 30% emission quota when capacities of the nuclear plants are determined endogenously in the model.

After these comparisons, notable remarks will be given in the light of these three comparisons. The section ends with the analysis elucidating how each sector is influenced under an economy-wide quota on cumulative emissions.

The analysis begins with comparing BC and BCq30. Figures 5.15 and 5.16 illustrate the comparison of BC and BCq30 in terms of electricity generation and primary energy supply. These two figures together indicate sharp decreases in electricity generation and primary energy supply when BC emissions are reduced by 30%. Following items are to explain the details of our observations:

- As seen in Figure 5.15, an immense decrease in electricity generated by the least carbon efficient plants, i.e., coal and lignite power plants, is observed. The decline in electricity generated by coal power plants amounts to 210 TWh by 2030 which corresponds to 73% decline compared to its BC level.

- The increase of renewable resources, both in Figure 5.15 and Figure 5.16, is owing to solar power plants which have not been utilized in the BC scenario. Note that solar power plats have the highest cost figures among electricity generation alternatives but are emission free technologies. Then, restricting GHG emissions by 30% conduces solar power plants to be feasible.

- Significant decreases are observed in primary energy demand of high-emission fuels such as coal and lignite, accompanied with a minor decrease in relatively cleaner natural gas. However, the actual reason of the decline in natural gas being so limited is the fact that natural gas demand in BC scenario was mainly determined by the lower bounds defined in the model (see Equations 4.46 and 4.49), but not relatively lower emission-rate of the natural gas.

- Note that there is no change in amount of electricity generated by petroleum products as seen in Figure 5.15. Then, the decline in primary supply of petroleum products (Figure 5.16) is all coming from the decline in non-electric use of petroleum products.

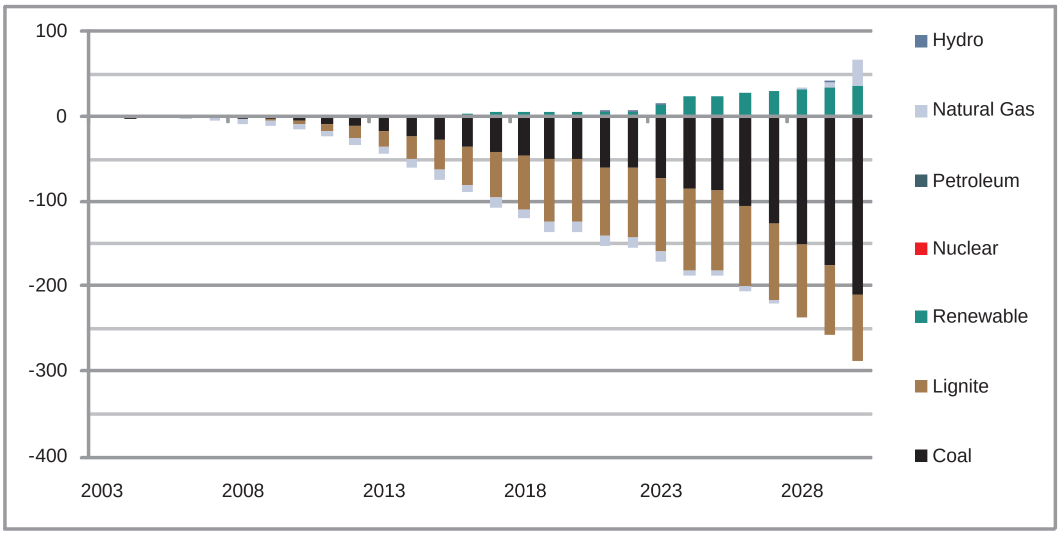


Figure 5.15: Electricity Generation: [BCq30-BC], TWh.

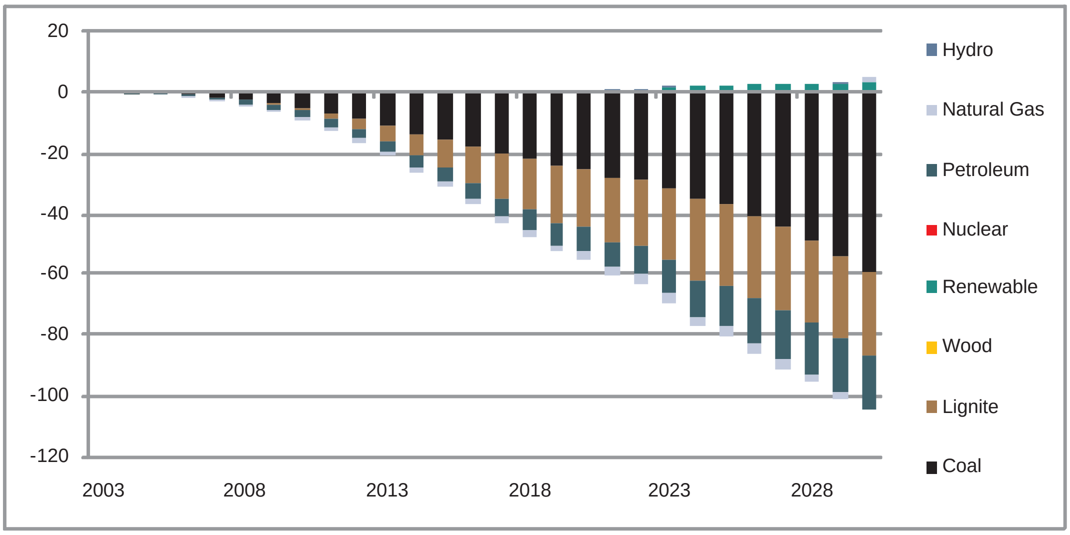


Figure 5.16: Primary Energy Supply: [BCq30-BC], Mtoe.

Figures 5.17 and 5.18 show comparison of NoN and NoNq30 in terms of electricity generation and primary energy supply. The most significant difference between these figures and those presented for the BC is the increase in natural gas power plants. The reason is obvious that the only solution to satisfy electricity demand for higher growth rates under GHG restrictions without a nuclear power programme is to utilize more natural gas plants which are cleaner compared to coal and lignite power plants.

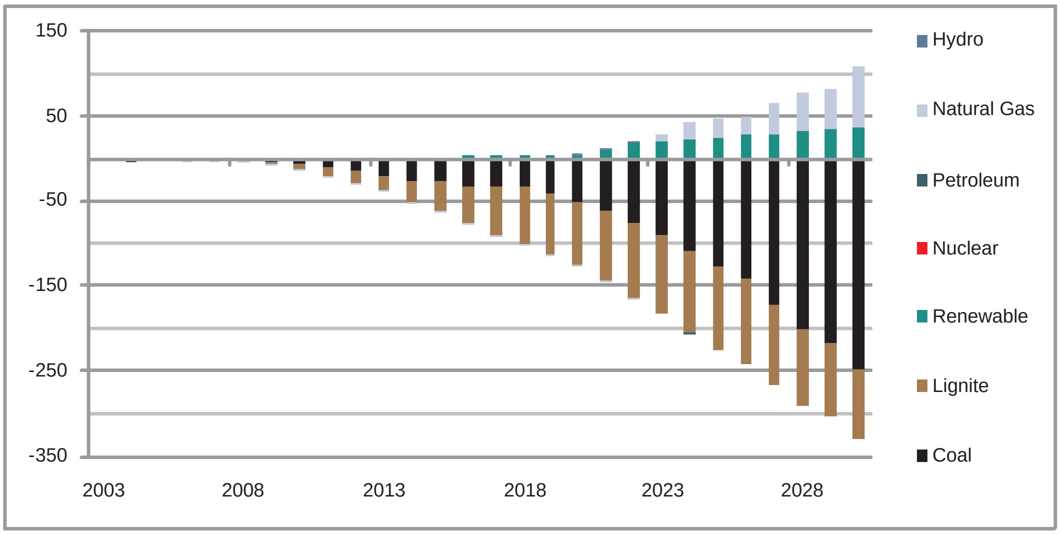


Figure 5.17: Electricity Generation: [NoNq30-NoN], TWh.

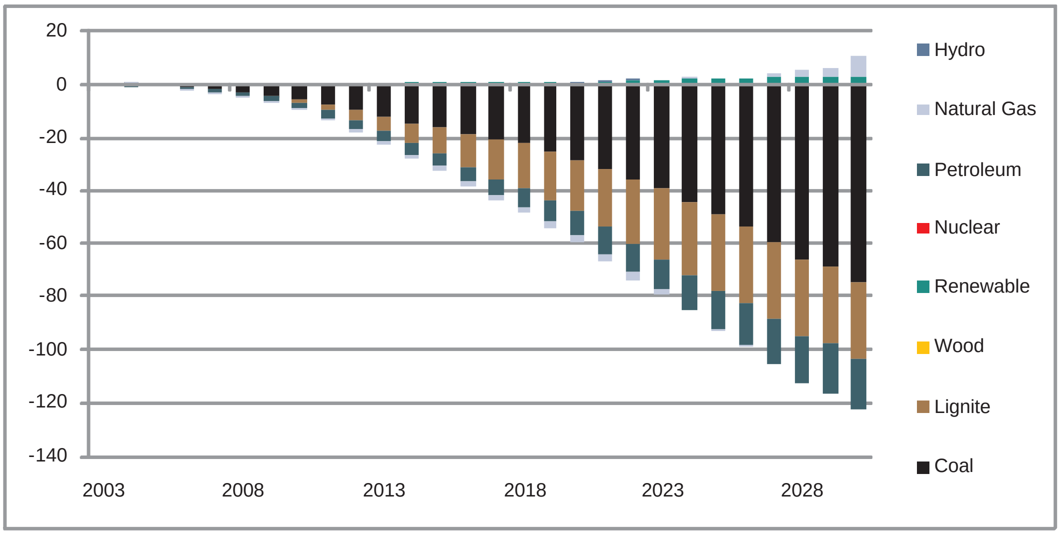


Figure 5.18: Primary Energy Supply: [NoNq30-NoN], Mtoe.

Figures 5.19 and 5.20 demostrate the comparison between OP and OPq30. As seen in these figures, restricting GHG emissions results in a significant increase of electricity generated by nuclear power plants. The result is more obvious from the Figures 5.21(a) and 5.21(b). These figures indicate that, potential nuclear capacity is completely utilized by the end of the planning horizon, which was around 50% (see Figure 5.14(b)) without the restrictions on the GHG emissions.

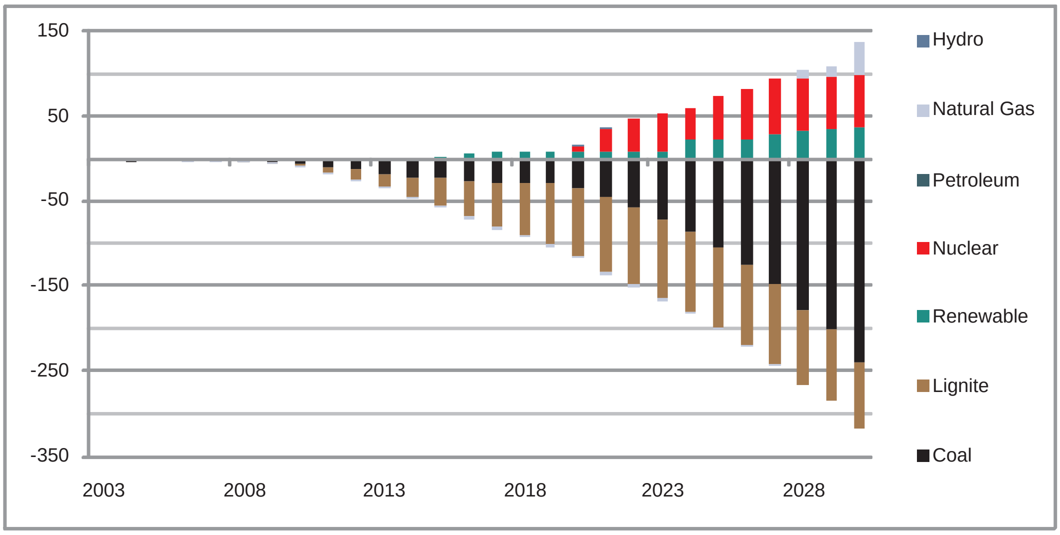


Figure 5.19: Electricity Generation: [OPq30-OP], TWh.

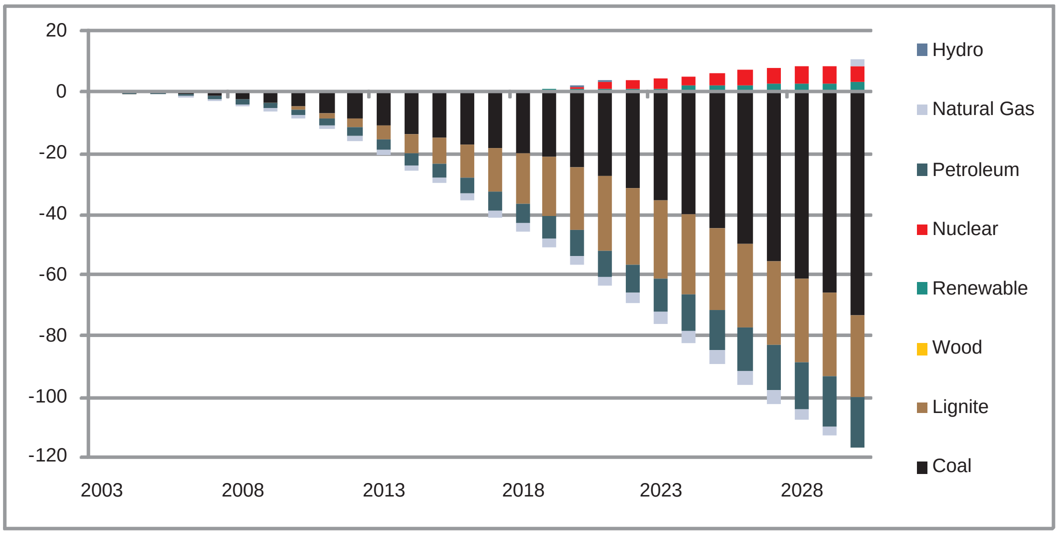
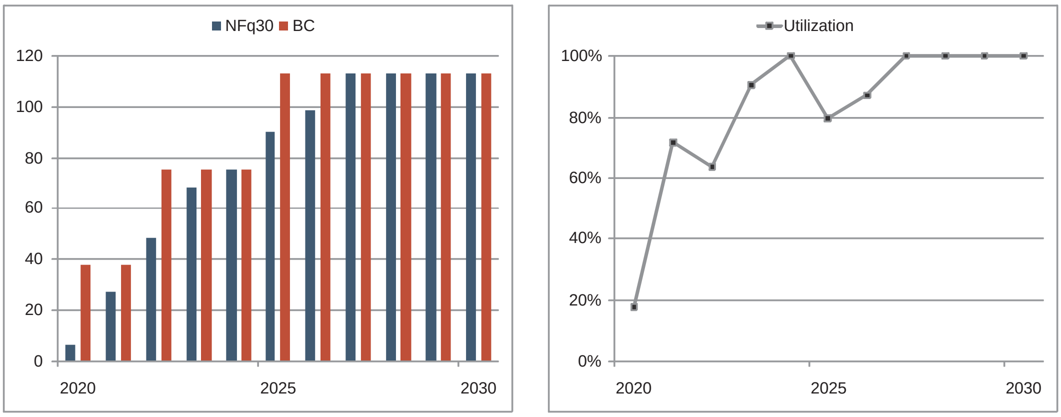


Figure 5.20: Primary Energy Supply: [OPq30-OP], Mtoe.

Figure 5.22 illustrates changes in GDP, final energy consumption, electricity generation and primary energy supply for each level of quota and under each setting. The following points are noteworthy regarding this figure and all pairwise comparisons. Note that the values given in this figure are calculated based on cumulative amounts.

- The nuclear plants, which are assumed to be emission free, provide a significant advantage under emission quotas. That is why the decline of energy related indicators in NoN is more dramatic compared to BC and OP as seen in Figure 5.22.



(a) TWh. (b) Utilization: Percentages of the BC Capacities.

Figure 5.21: Nuclear Electricity: BC vs OPq30.

- Percentage change in GDP is also higher for NoN compared to BC and OP due to higher decrease in energy inputs as pointed out in the first item. The decrease in cumulative GDP exceeds 10% for NoN when a 40% reduction in GHG emissions is forced.
- Restricting GHG emissions favors the energy resources with low emission rates. That is why the decline in final energy inputs is always significantly less than the level of reduction in GHG emissions, e.g., a 30% reduction of GHG emissions in the BC scenario results in less than 20% decline in final energy consumption as seen in Figure 5.22.
- Renewable resources have a crucial importance under emission quotas. It has been observed that limited capacity of renewable resources, even for the solar power plants with extremely high cost figures, are fully utilized when the emissions are restricted.
- In case no nuclear programme is implemented, natural gas power plants which are cleaner compared to coal and lignite plants play a key role in satisfying electricity demand regarding the limited capacities of renewable resources.

Finally, Figures 5.23 and 5.24, are presented to reveal how sectors are influenced in terms of value-added when an economy-wide quota is set on total cumulative GHG emissions without addressing a specific sector. Figures 5.25 and 5.26, on the other hand illustrate the changes in sectoral final energy consumptions. These figures indicate that *Energy-intensive Industry* is the sector which has been influenced at most in case of a restriction on emissions. This sector is followed in order by *Other Industry*, *Transportation*, *Services* and *Agriculture*, respectively.

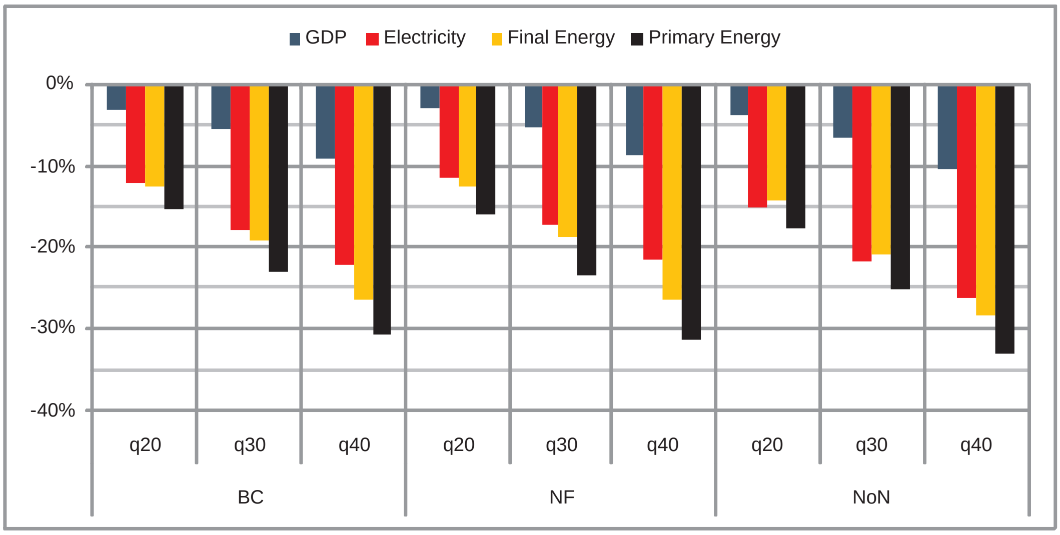


Figure 5.22: Changes in Main Indicators Under Quotas: BC, NoN and OP, Percentages of the Corresponding Base Runs.

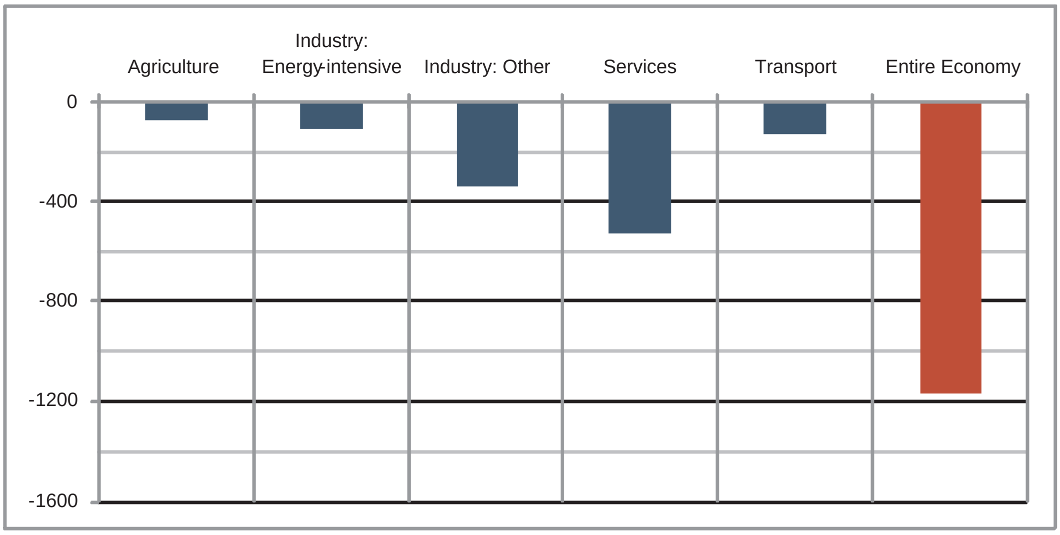


Figure 5.23: Change in Sectoral VAs: [BCq30-BC], Billions TL.

This result is in accordance with the emission intensities, ratio of sectoral GHG emissions to sectoral value-added, presented in Table 5.4.

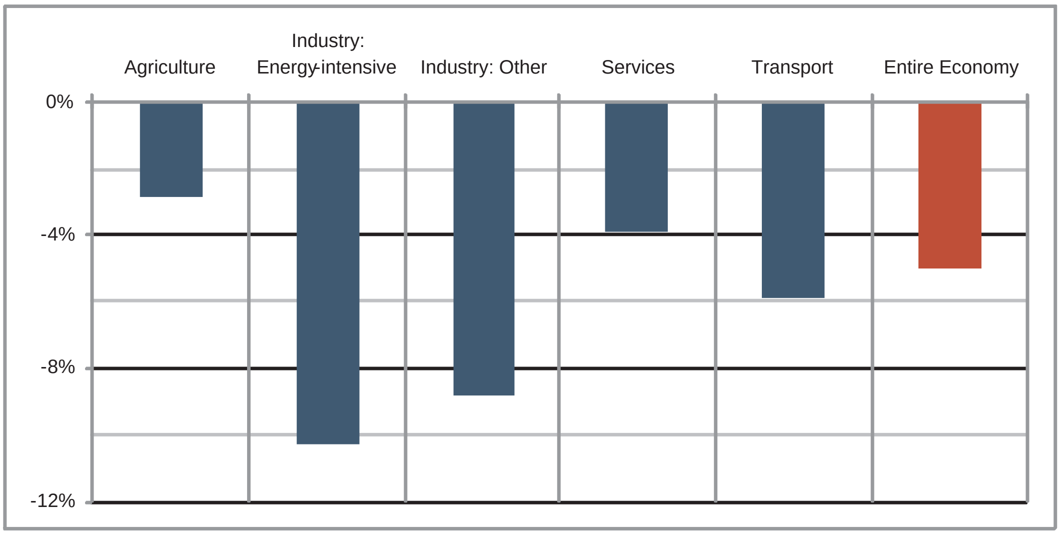


Figure 5.24: Change in Sectoral VAs: [BCq30-BC], Percentages of the Cumulative BC Levels.

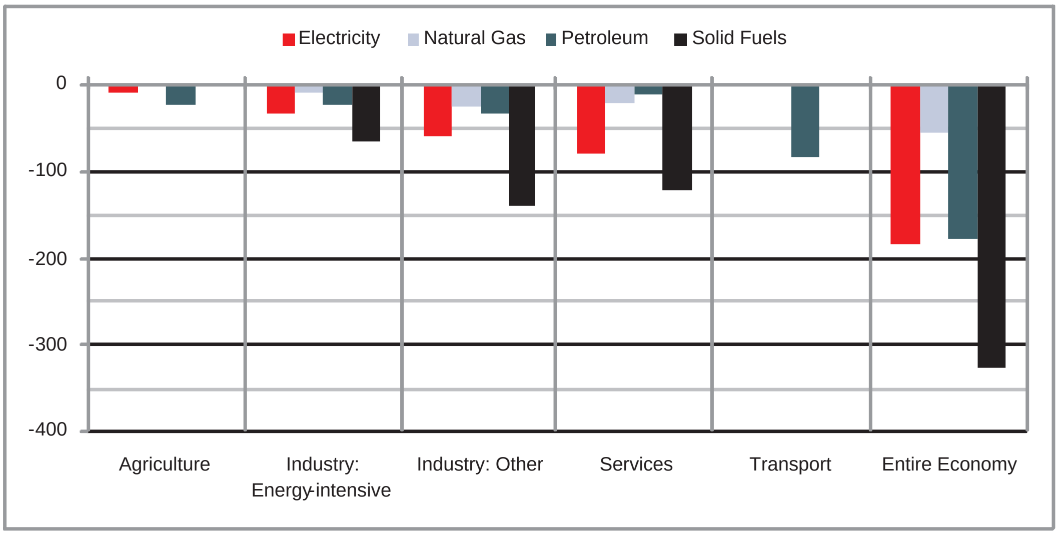


Figure 5.25: Change in Sectoral Final Energy Consumptions: [BCq30-BC], Mtoe.

Table 5.4: Emission Intensities, kg/TL.

	Emission Intensity
Agriculture	0.286
Industry: Energy-intensive	2.231
Industry: Other	1.244
Services	0.335
Transportation	0.954
Entire Economy	0.622

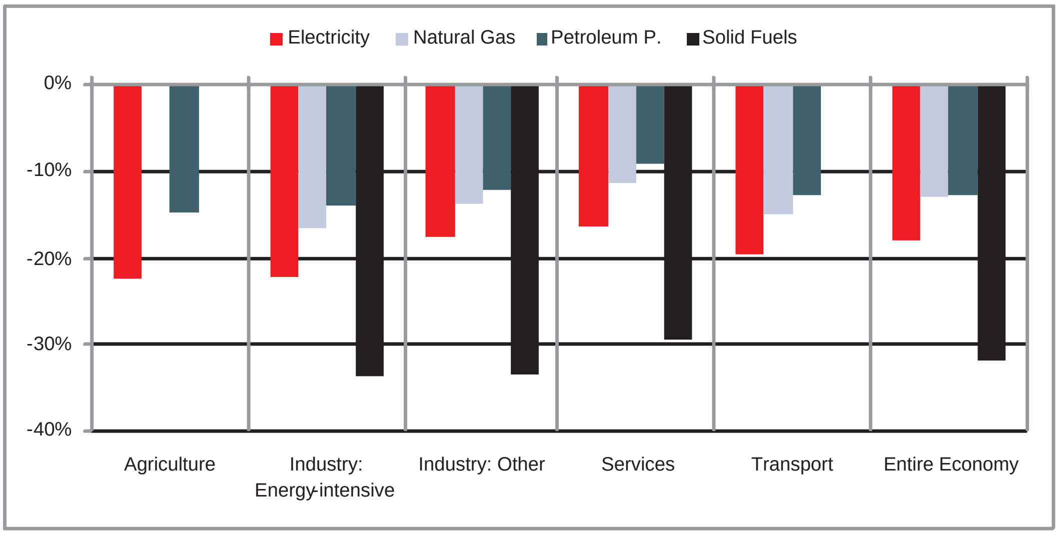


Figure 5.26: Change in Sectoral Final Energy Consumptions: [BCq30-BC], Percentages of the BC Levels.

5.5 POWER PLANTS COUPLED WITH CCS TECHNOLOGY

We have discussed how power plants coupled with CCS technology were embedded into our model in Section 5.1.2. In this section, we will first give a brief information about CCS technology and then try to analyze the impacts of employing this technology in coal, lignite and natural gas power plants.

CCS technologies have gained importance with the emerging threats caused by significant increase in CO_2 emissions and concomitant global warming. In fact, it is not a new technology since it has been earlier investigated that injecting CO_2 into oil or gas fields lead to getting additional oil or gas (EOR, Enhanced Oil Recovery). There are successful applications in the world such as the ones in Canada, Algeria, Netherlands and Norway.

The first step in CCS process is the separation of CO_2 from the other gases emitted by industrial or energy related activities. The CO_2 captured in the first step is then transported via pipelines, railway or roadway to the places in which it will be stored. Potential places to store the captured CO_2 are oil and gas fields, unminable coal beds, deep saline formations and oceans. The reader is referred to [57] for more information about technical details, cost figures and current status of the CCS technology.

Although the potential of CO_2 storage capacity has not yet been analyzed for Turkey, deep aquifers, for which sufficient data are not available, are thought to be promising according to the experts' opinions, [58]. In our model, the potential capacities of CCS integrated plants are assigned also based on [58]. It is assumed that 500 MWs of CCS integrated coal, lignite and natural gas power plants would be available after 2013 with increments of 500 MWs for each type in every five years.

Our numerical experiments, with no surprise, show that the CCS integrated power plants have not been selected by the model in the no-abatement setting due to the high investments required to implement this technology. Then, our model was run for the three levels of quotas, i.e., quotas restricting cumulative GHG emissions by 20%, 30% and 40%, under the BC setting. Results pertaining to each level of quota and for each setting can be seen in Appendix H.2. However, an illustrative set of results, results under a 70% quota (equivalently 30% reduction in cumulative GHG emissions) in the BC setting (BCccsQ30), are used for the analysis performed in this section.

Figures 5.28, 5.27 and 5.29 compare BCq30 and BCccsQ30 with respect to electricity generation, primary energy supply and final energy consumption, respectively. Following observations are immediate from these figures:

- Lignite and coal-fired power plants coupled with CCS technology are commissioned before natural gas plants coupled with the same technology. Two main reasons lie behind this observation. First, coal and lignite plants have relatively lower cost figures compared to natural gas plants. Second, coal and lignite plants grant a higher level of emission saving per unit of electricity.
- CCS integrated plants replace the conventional plants of the same types at most. That is, increases in CCS integrated coal, lignite and natural gas power plants are accompanied with decreases in conventional plants of these types.
- CCS integrated plants also replace a small amount of solar electricity which has the highest cost figures among all electricity generating options.
- As seen in Figure 5.29, emission gains due to the utilization of CCS-integrated plants opens a room for non-electric use of some petroleum products and lignite.

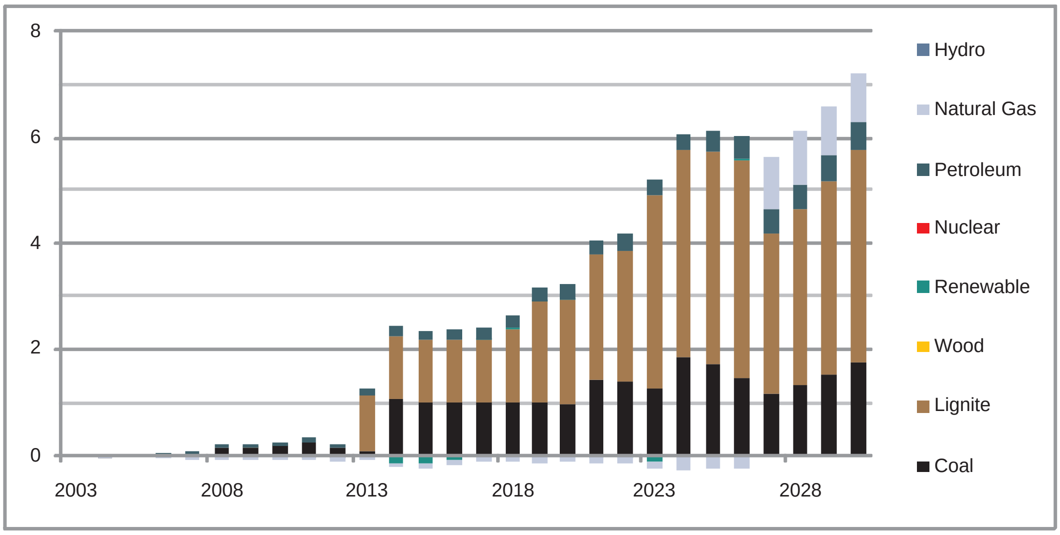


Figure 5.27: Primary Energy Supply: [BCccsQ30-BCq30], Mtoe.

Figure 5.28 compares BC and BCccs scenarios in terms of main indicators under each level of quota. This figure indicates a 2.2% increase in electricity generation and 0.3% increase in

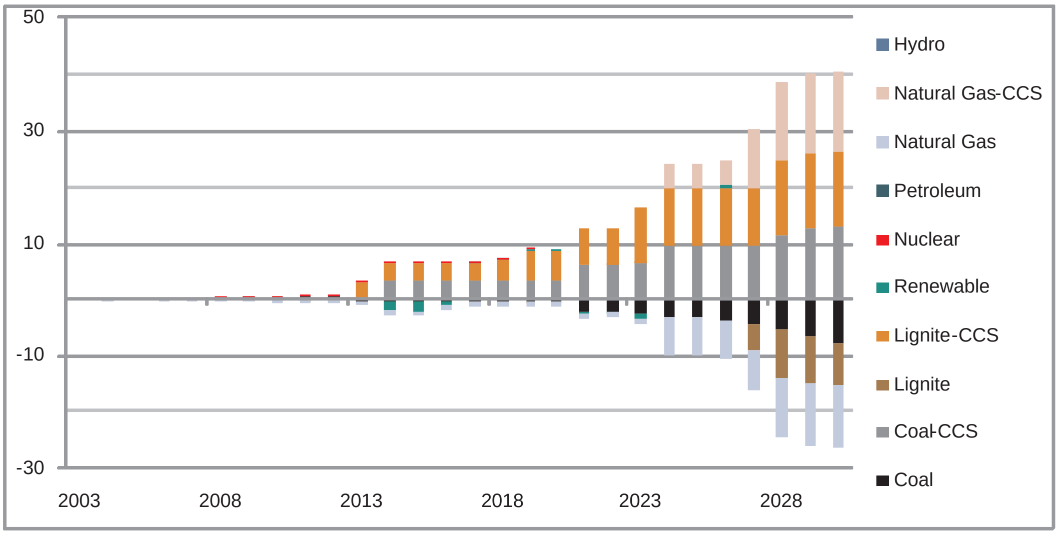


Figure 5.28: Electricity Generation: [BCccsQ30-BCq30], TWh.

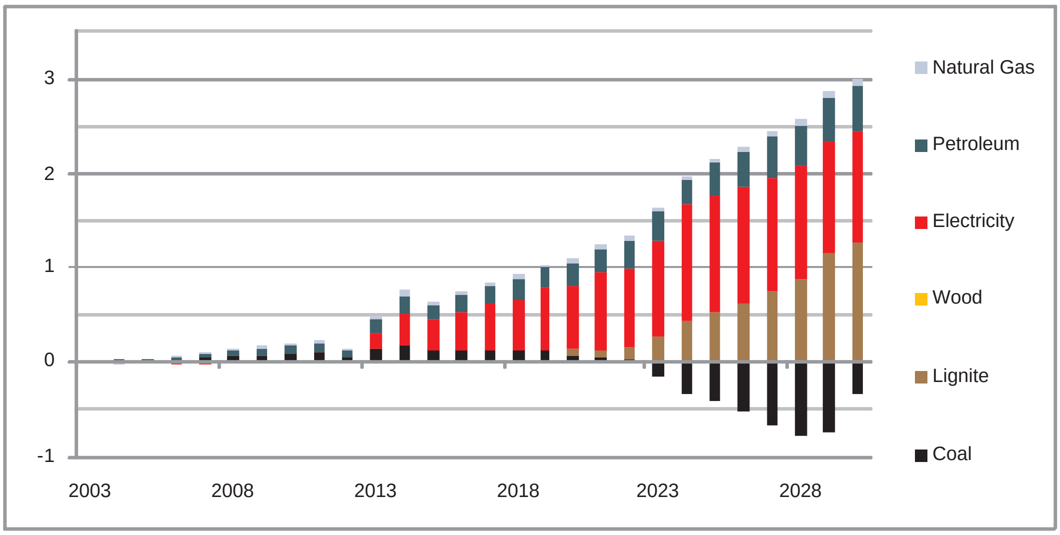


Figure 5.29: Final Energy Demand: [BCccsQ30-BCq30], Mtoe.

GDP under a 40% restriction on GHG emissions. Figure 5.31, on the other hand, illustrates the utilization of CCS integrated plants. As seen in this figure, utilization of these plants significantly increase in case of a 30% reduction in GHG emissions compared to a 20% reduction. However, utilization level under a 40% reduction in GHG emissions is approximately the same as it is under a 30% reduction. That means; the level of shrinkage in the economy under BCccsQ40 scenario is so dramatic that utilization of CCS integrated plants as well as all energy and economic variables cannot go behind a certain threshold.

To conclude, analysis performed in this section reveals that the CCS technology would bring

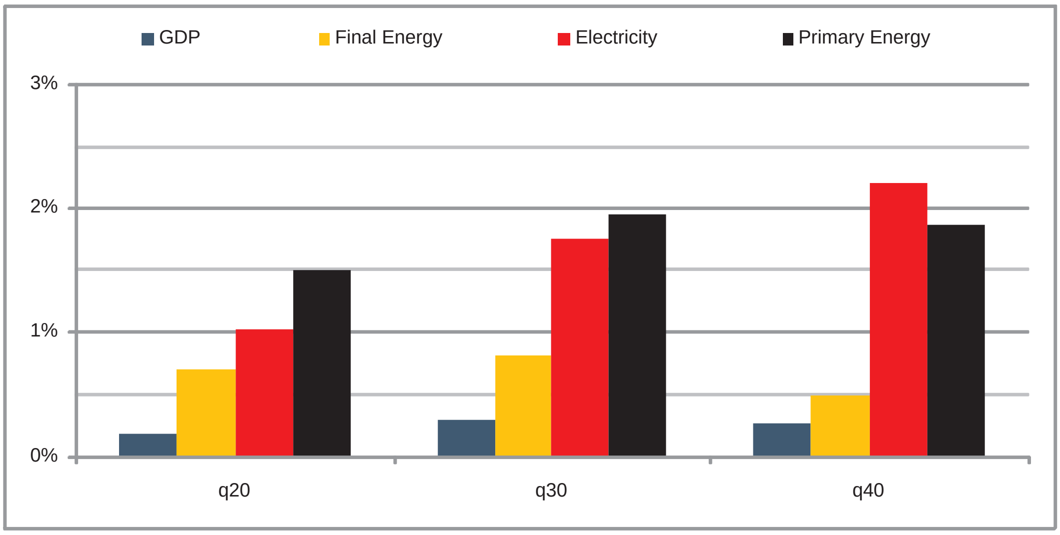
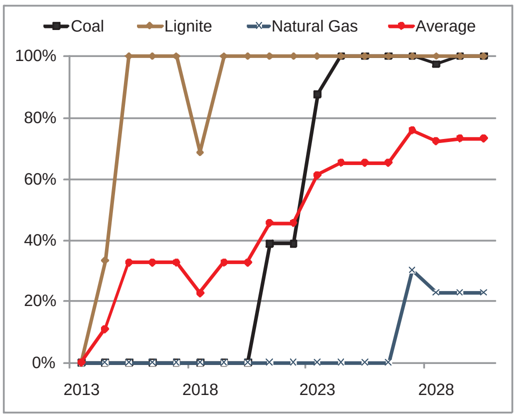
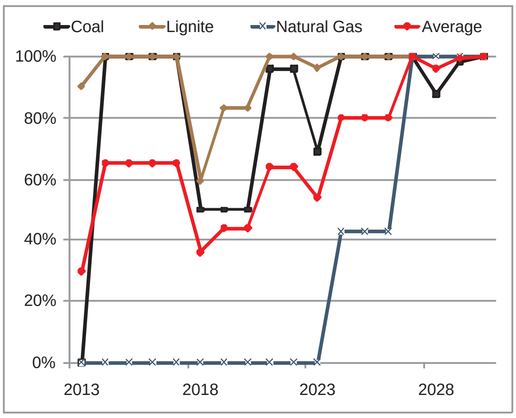


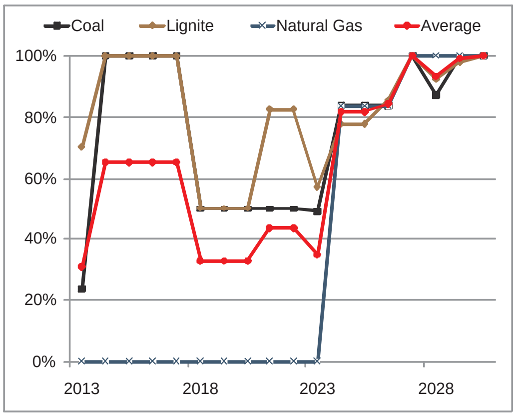
Figure 5.30: Main Indicators: [BCccs-BC], Percentages of the BC Levels.



(a) BCccsQ20.



(b) BCccsQ30.



(c) BCccsQ40.

Figure 5.31: Utilization of Power Plants Coupled with CCS Technology.

benefits under emission restrictions. However, to obtain significant benefits owing to this technology requires a programme with a broader scope, that is, capacities as small as those used in this study have minor impacts on the economy.

5.6 QUOTAS SET ON SECTORAL GHG EMISSIONS

In this section, quotas on sectoral emissions are implemented instead of setting a single economy-wide quota. Aq30, IEq30, IOq30, Sq30 and Tq30 represent the scenarios in which a 30% reduction in sectoral emissions is forced individually for the sectors *Agriculture*, *Industry: Energy-intensive*, *Industry: Other*, *Services* and *Transportation*, respectively. Detailed results for these scenarios are tabulated in Appendix H.3. In the rest of this section, comparison of these scenarios based on deviations of each scenario from the reference case, the BC scenario, will be presented.

Figures 5.32 and 5.33 show how final energy consumption is influenced in case of a 30% restriction in sectoral GHG emissions, as actual values and as percentages of the cumulative BC emissions, respectively. Note that the results presented in these figures are calculated based on cumulative amounts. The figures imply that the final energy consumption is mostly influenced when a quota is set on the emissions arising in *Transportation* sector. This result is not surprising given that almost all of the final consumption in this sector consists of petroleum products, see Table B.4 for sectoral final energy consumptions and Table D.1 for the share value of petroleum products in *Transportation* sector ($sp_{Transportation}$). That is, there is no way for *Transport* to decrease its sectoral GHG emissions other than cutting petroleum products consumption. In other words, the substitution possibilities among energy inputs is extremely low for the *Transportation* sector.

Figures 5.34 and 5.35 compare sectoral quota policies in terms of GDP, final energy consumption, electricity generation and primary energy supply. Following remarks are noteworthy regarding our observations from these figures.

- Setting quotas on sectoral emissions of *Energy-intensive Industry*, *Other Industry* and *Services* sectors mainly influences the final consumption of solid fuels. Decrease in

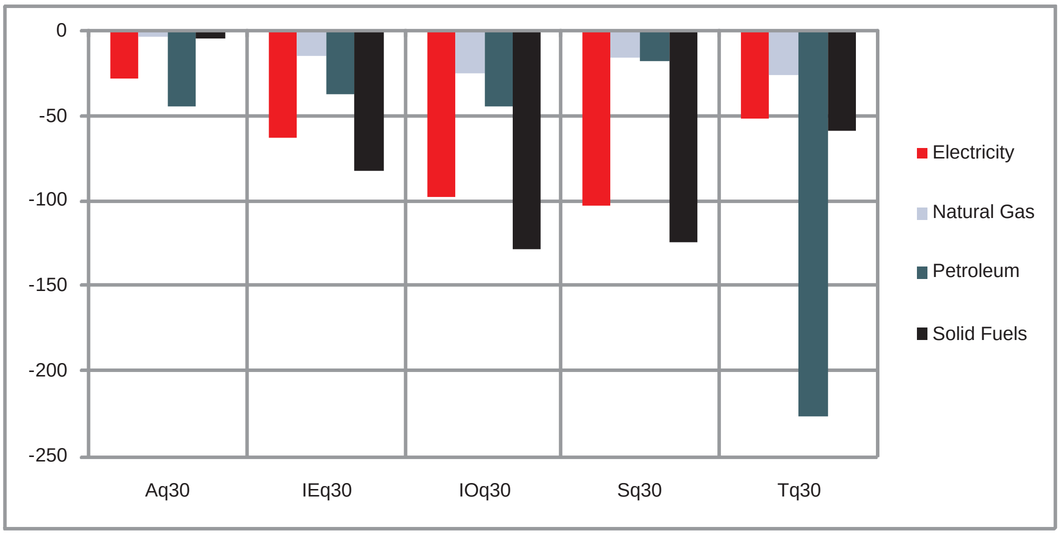


Figure 5.32: Final Energy Demand: [Aq30-BC], [IEq30-BC], [IOq30-BC], [Sq30-BC], [Tq30-BC], Mtoe.

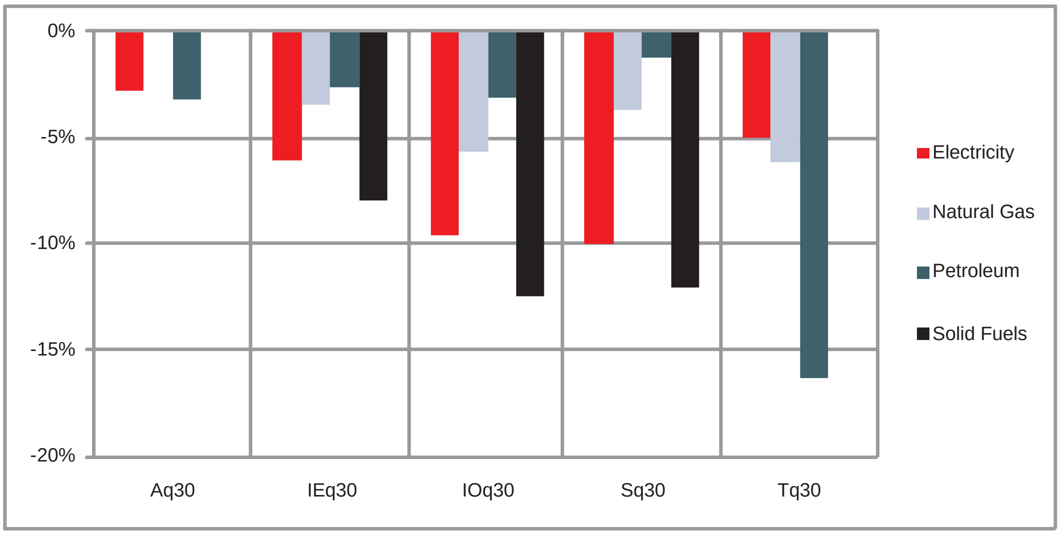


Figure 5.33: Final Energy Demand: [Aq30-BC], [IEq30-BC], [IOq30-BC], [Sq30-BC], [Tq30-BC], Percentages of the BC Levels.

solid fuels is followed in order by the decreases in final consumptions of electricity, natural gas and petroleum products.

- As discussed in the previous paragraphs, quotas set on sectoral emission of *Transportation* sector results in a sharp decrease in final consumption of petroleum products.
- The severity of the impacts resulting from the quotas set on the sectors with high electricity consumption is alleviated to some extend since emission intensity of electricity generation significantly decreases in case of large declines in electricity generation.

That is, the model selects low emission technologies for generating electricity under emission constraints. That is why emission intensity of generating electricity, GHG emissions divided by generation amounts, is 0.87 kg/MWh for IEq30 while it is 0.75 kg/MWh for Sq30.

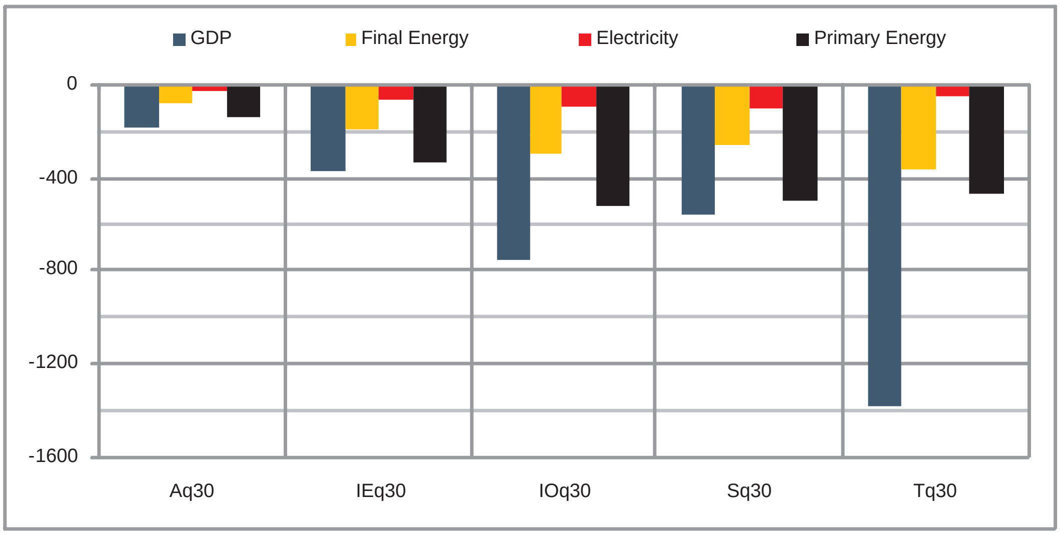


Figure 5.34: Main Indicators: [Aq30-BC], [IEq30-BC], [IOq30-BC], [Sq30-BC], [Tq30-BC].

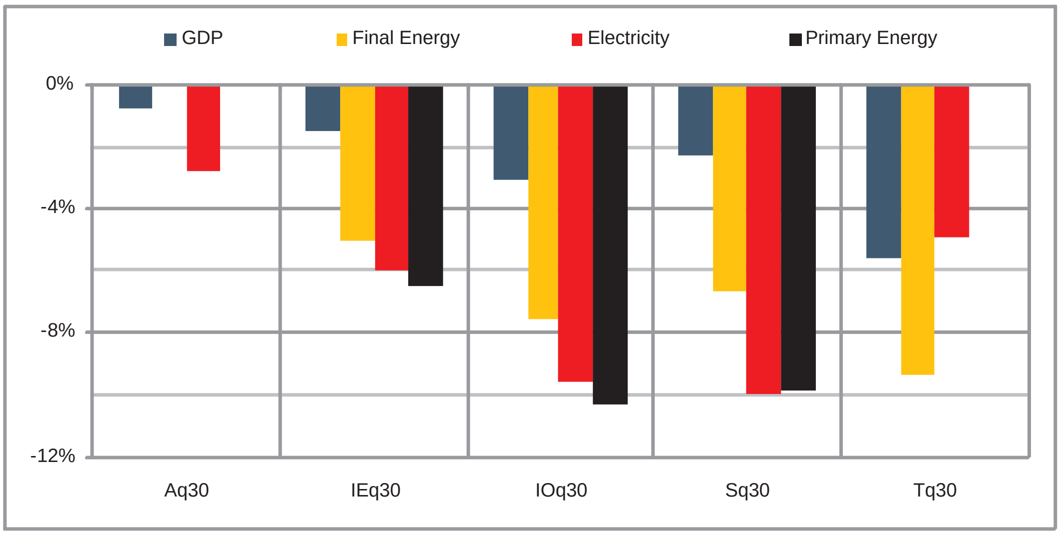


Figure 5.35: Main Indicators: [Aq30-BC], [IEq30-BC], [IOq30-BC], [Sq30-BC], [Tq30-BC], Percentages of the BC Levels.

Finally, Figure 5.36 concludes the analysis. This figure displays the emission intensity of final energy consumption in each sector, i.e., total sectoral emission of a sector divided by final energy consumption in the given sector, assigning an index of 100 for the BC intensities. Then, as clearly seen in this figure, it is the services sector in which the decrease in emission intensity is at most in case of a sectoral quota policy. This observation indicates the capability of services sector in evolving to a lower emission sector by rearranging its energy bundle. In other words, substitution possibilities among energy inputs is more in services sector compared to other sectors. Note that, transportation sector has almost no substitution possibility among its energy inputs.

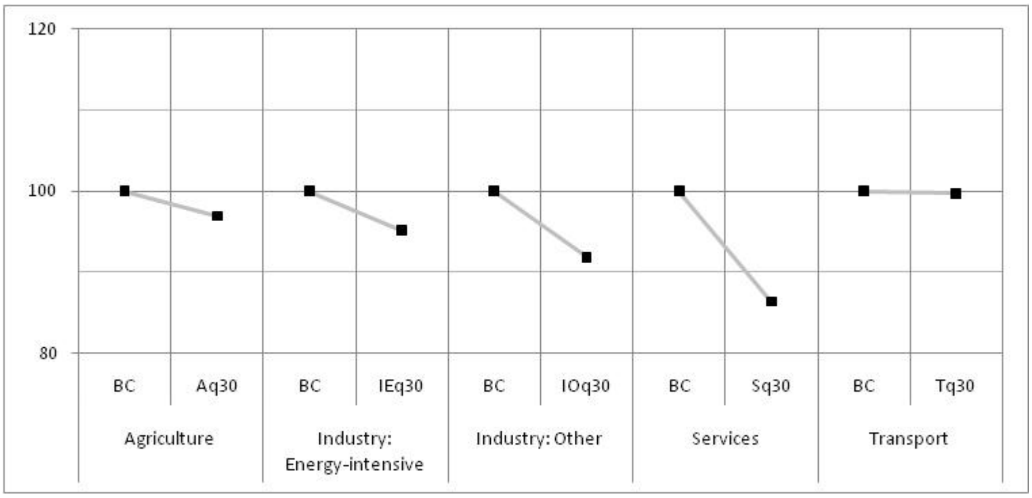


Figure 5.36: Sectoral GHG Intensity Indices: BC vs Sectoral Quota Scenarios.

5.7 CHANGES IN IMPORTED FUEL PRICES

Turkey depends heavily on energy imports; domestic resources accounted for only 28.57% of the total primary energy supply in 2009. Changes in world energy prices can therefore produce significant variations in macroeconomic balances. In this section we investigate the likely consequences of world price changes under two scenarios; a high price scenario (BC-high) and a low price scenario (BC-low), as taken from WEO 2010, [55]. Full results for these scenarios are given in Appendix H.4. Price projections for imports of crude oil, natural gas and hard coal used in all scenarios, except BC-high and BC-low, are tabulated in Appendix B.2, in Tables B.8, B.9 and B.10, with detailed explanations of how they were obtained. Projections used in BC-high and BC-low are given in Table 5.5. This table also includes price data for BC for easy comparison. The projections in Table 5.5 are raw data which needs to be processed according to model requirements, that is figures are first converted into 2003 TL and then adjusted as explained in Appendix B.2.

Table 5.5: Price Projections for World Energy Prices: BC, BC-low and BC-high, [55].

		Crude Oil $/barrel	Natural Gas $/MBtu	Coal $/tonne
BC	2015	90.4	10.6	97.7
	2020	99	11.6	101.7
	2025	105	12.3	104.1
	2030	110	12.9	105.6
	2035	113	13.3	106.5
BC-high	2015	94	10.7	97.8
	2020	110	12.1	105.8
	2025	120	12.9	109.5
	2030	130	13.9	112.5
	2035	135	14.4	115
BC-low	2015	87.9	10.4	92.5
	2020	90	10.6	85.8
	2025	90	10.7	75.8
	2030	90	10.9	66.3
	2035	90	11	62.1

In the rest of this section, we will present our analysis for BC-high and BC-low scenarios in a similar way as we did in the previous sections, i.e., comparing solution of these scenarios to those of BC. Detailed computations for BC-high and BC-low can be seen in Appendix H.4.

Figures 5.37 and 5.38 display changes in primary energy supply and electricity generation, respectively, in case of low energy prices. Our findings obtained from these figures are as follows:

- Significant increases are observed in imports of coal, natural gas and petroleum products with a sum of more than 25 Mtoe by 2030.
- Decrease in natural gas price causes a slight increase in natural gas plants in the first years of the horizon. This additional capacity replaces some of coal, lignite and wind plants.
- Sharp decrease in coal price after 2020 adds to both electric and non-electric consumption of coal.

Figures 5.39 and 5.40 illustrate the break-down of changes in final energy demand by main energy category for each sector as well as for the overall economy, in actual amounts and also

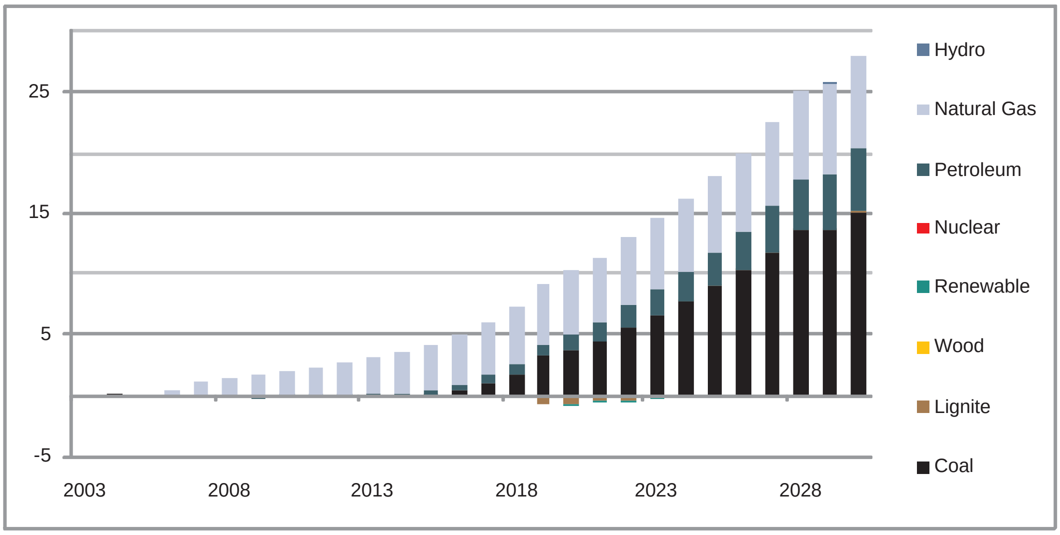


Figure 5.37: Change in Primary Energy Demand by Energy Type under Low World Energy Prices: [BClow-BC], Mtoe.

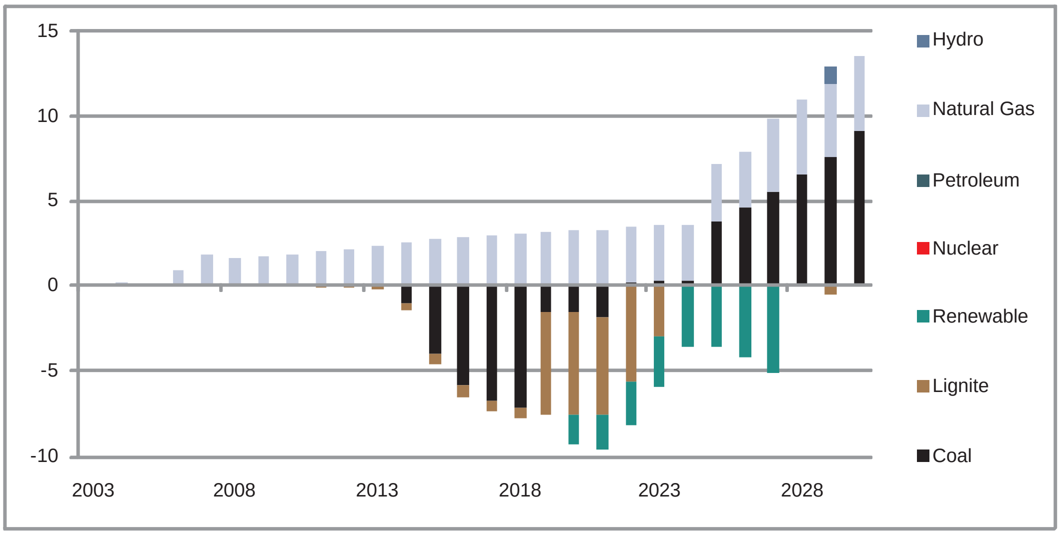


Figure 5.38: Change in Electricity Demand by Technology Type under Low World Energy Prices: [BClow-BC], TWh.

as percentages of corresponding BC levels. Conclusions to be drawn from these figures are:

- Decrease in world energy prices boosts gas consumption which was mostly calculated at lower bounds in the BC scenario.
- The increase in oil consumption is mainly due to *Transportation* sector which has the share of petroleum products in its energy bundle at highest among all sectors.
- *Energy-intensive Industry* is the sector with the highest energy intensity, energy con-

sumed per Turkish lira of value-added is very high in this sector compared to other sectors (see Table 5.6 for sectoral energy intensities). That is one of the reasons why this sector could not compete with other sectors which have higher potentials to increase their value-added by additional energy input.

- *Services* and *Other Industry* are the sectors which benefit most from cheaper energy.

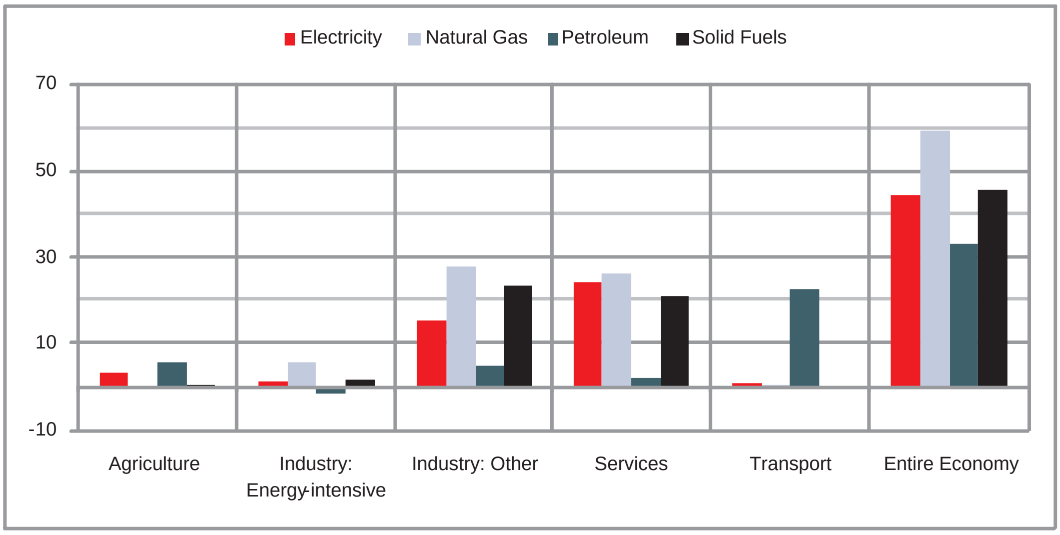


Figure 5.39: Change in Final Energy Demand by Energy Type under Low World Energy Prices: [BClow-BC], Mtoe.

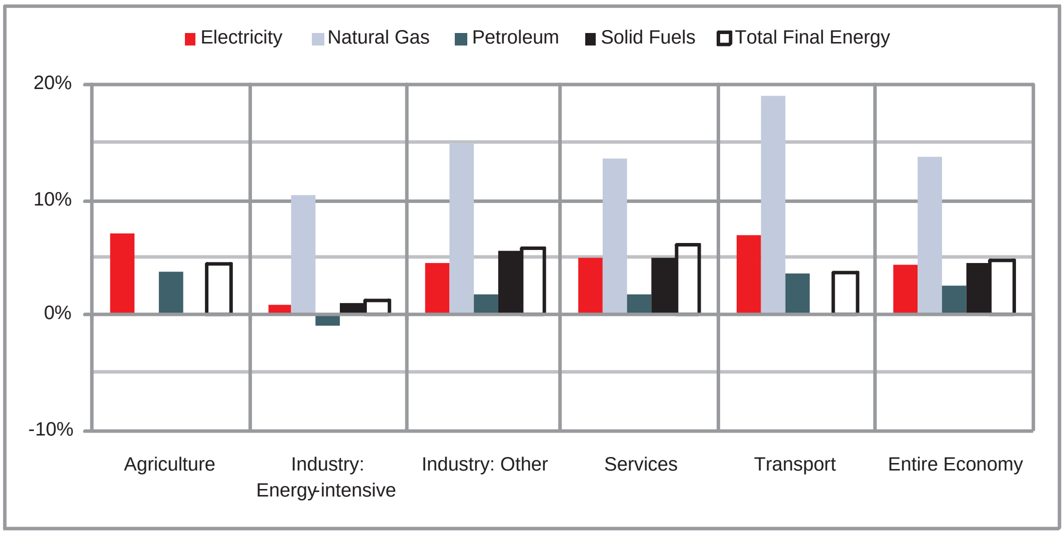


Figure 5.40: Change in Final Energy Demand by Energy Type under Low world energy prices: [BClow-BC], Percentages of the BC levels.

Figures 5.41 and 5.42 display the comparison between BC-high and BC in terms of primary

Table 5.6: Sectoral (Final) Energy Intensities, toe/1000 TL.

	Final Energy Intensity
Agriculture	0.080
Industry: Energy-intensive	0.567
Industry: Other	0.313
Services	0.090
Transportation	0.309
Entire Economy	0.167

energy and electricity demand, respectively. Following observations can be made.

- As seen in Table 5.5, the degree of deviation from BC prices is lower for BC-high compared to BC-low. That is why the rate of decrease in 5.41 and 5.42 is lower than the rate of increase observed in Figures 5.37 and 5.38. The decrease in primary energy demand is just below 10 Mtoe while the corresponding increase was more than 25 Mtoe for BC-low.
- Increasing world energy prices mainly influence the demand for primary coal and petroleum products. The decrease in natural gas demand is relatively less compared to coal and petroleum products due to the lower bounds in the model.
- Significant decline is observed in coal consumption accompanied with some natural gas in the power industry. Marginal falls in wind and lignite plants are due to the overall shrinkage in the economy.

Changes in sectoral final energy consumptions under high world energy prices are shown in Figures 5.43 and 5.44, as actual amounts and percentages of corresponding BC levels. Following remarks can be made:

- As mentioned above, oil prices increase faster than coal and natural gas prices. Moreover, the consumption of natural gas mostly takes place at its minimum level in the BC scenario. These two facts explain the huge decrease in demand for petroleum products in the BC-high scenario.
- The facts pointed out in the first remark supports the following observation. In case of price decreases, the increase in petroleum consumption was mainly due to the *Trans-*

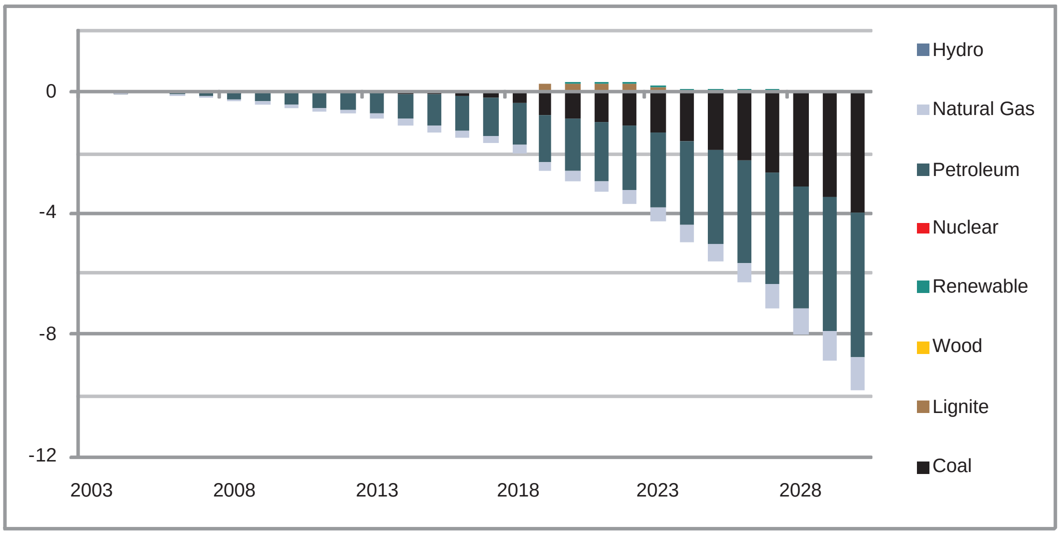


Figure 5.41: Change in Primary Energy Demand by Energy Type under High World Energy Prices: [BChigh-BC], Mtoe.

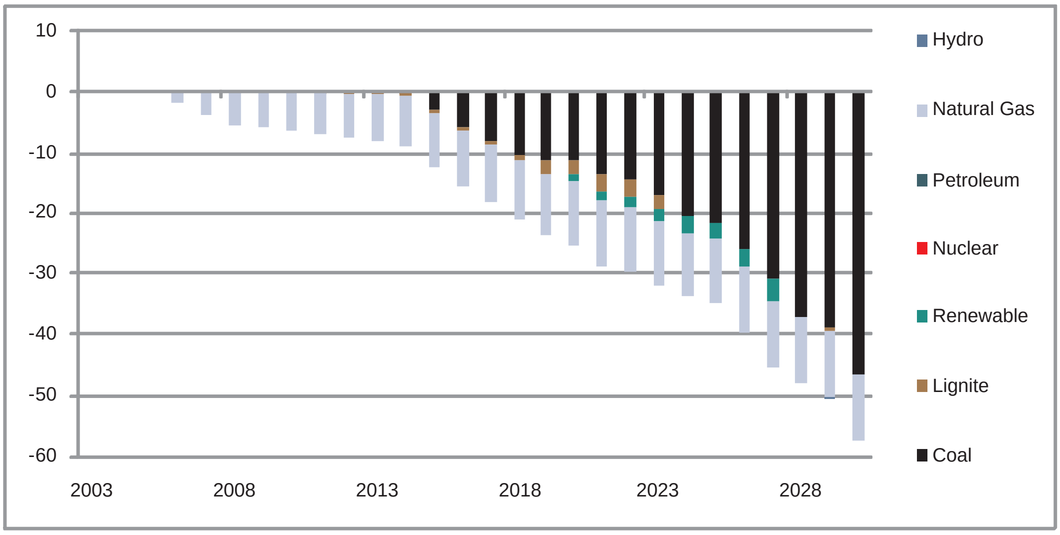


Figure 5.42: Change in Electricity Demand by Energy Type under High World Energy Prices: [BChigh-BC], TWh.

portation sector as noted before. However, in the BC-high scenario, the decrease in oil consumption is shared among all sectors since the increase in coal price is not as high as to result in a significant change in coal consumption and it is not possible for the sectors to decrease their natural gas consumption due to corresponding lower bounds. Then, getting rid of expensive oil as much as possible is valuable not only for *Transportation* sector but also for the other sectors.

- As seen in Figure 5.44, the sector with the highest decline in final energy consumption is the *Agriculture* sector due to its low energy intensity as well as limited substitution opportunities in this sector. *Energy-intensive Industry*, on the other hand, has been influenced at least as it was the case in the BC-low scenario.

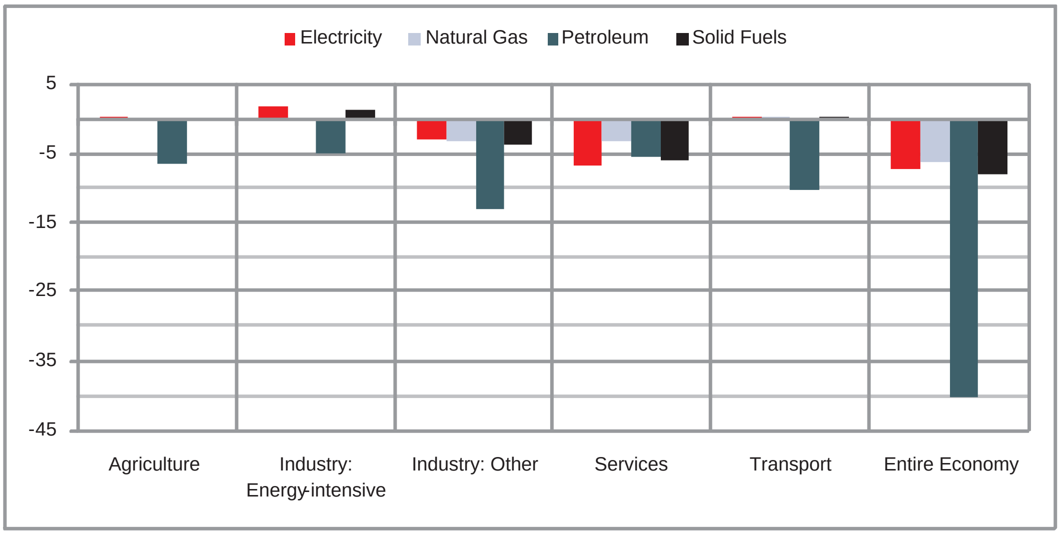


Figure 5.43: Change in Final Energy Demand by Energy Type under High World Energy Prices: [BChigh-BC], Mtoe.

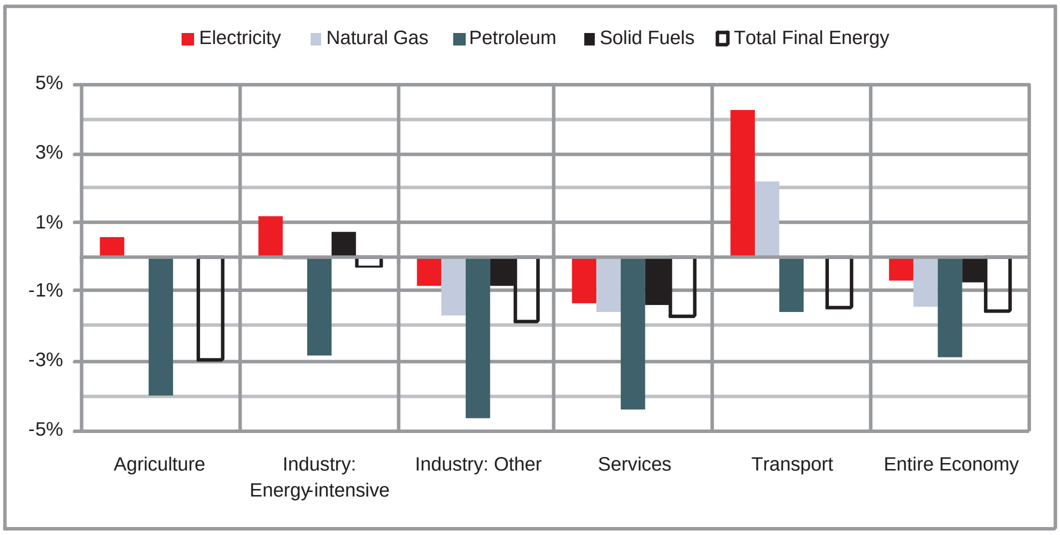


Figure 5.44: Change in Final Energy Demand by Energy Type under High World Energy Prices: [BChigh-BC], Percentages of the BC Levels.

We conclude this section with the following two figures. Changes in sectoral value-addeds and energy costs are demonstrated in Figures 5.45 and 5.46, respectively as percentages of the corresponding BC levels. In addition to comments already made, we can note the following.

- As seen in Figure 5.45, *Services* and *Industry: Other* are the sectors in which the changes in world energy prices cause higher deviations in value-added.
- As seen in Figure 5.46, in case of a decrease in world energy prices, the highest decrease in sectoral energy cost has been observed in the *Energy-intensive Industry* with a decrease of 10% compared to that of BC. This observation explains why increase in value-added in *Energy-intensive Industry* is relatively high although the increase in final energy inputs are negligible compared to other sectors, i.e., decline in energy prices provides a significant saving in the sector.
- Under BC-high scenario, the highest increase with respect to sectoral energy cost occurs in *Transportation* sector which has almost no substitution possibility among energy inputs.

To conclude, the overall effect of price changes is a resultant of a number of factors. Among those, following factors are found to be dominant in shaping the final structure of the economy based on our computations and observations summarized in this section.

- Sectoral energy intensities,
- Substitution possibilities among energy inputs in the sectors.

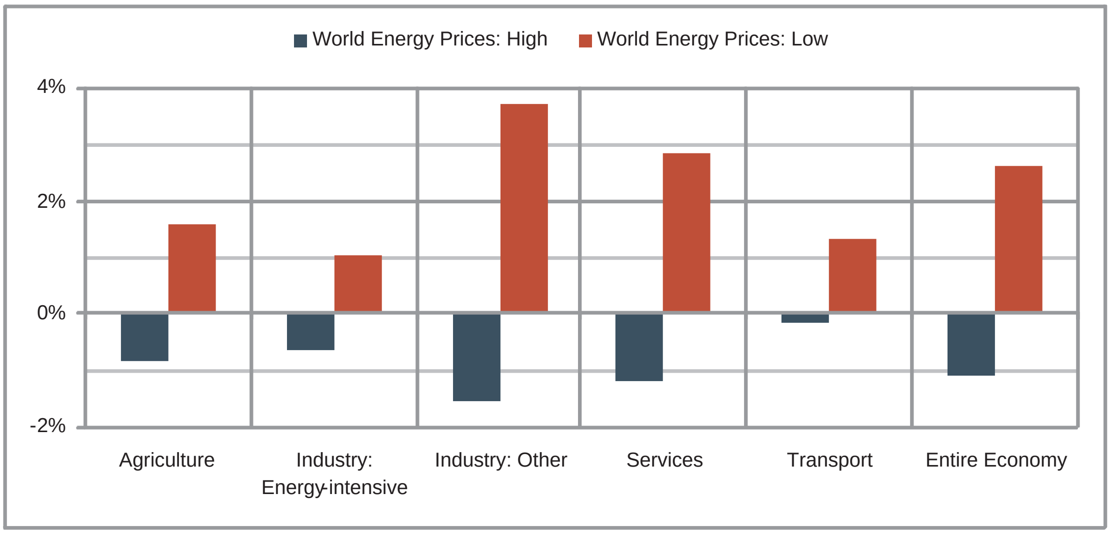


Figure 5.45: Changes in Sectoral VAs under Low and High World Energy Prices: Percentages of the BC Levels.

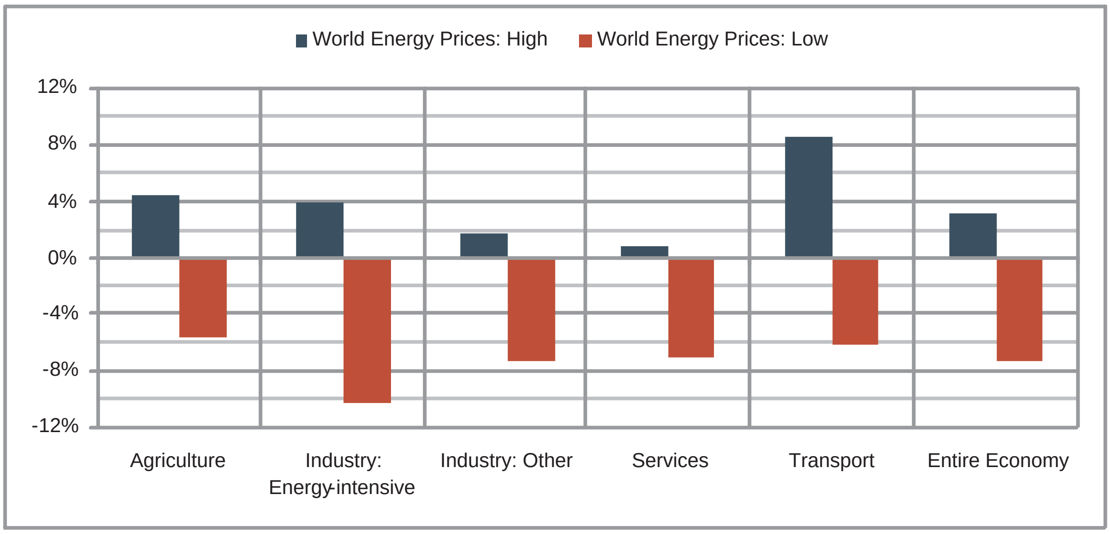


Figure 5.46: Changes in Sectoral Energy Costs under Low and High World Energy Prices: Percentages of the BC Levels.

Table 5.7: Main Indicators.

Year	BC	OP	NoN	BCq30	OPq30	NoNq30	BCccsQ30
GDP, 2003 prices, Billions TL.							
2010	596.57	596.53	596.52	588.94	589.24	588.10	589.19
2015	759.10	758.65	758.70	730.50	731.24	727.61	732.01
2020	969.19	968.08	968.58	911.04	912.06	903.52	914.13
2025	1239.64	1237.56	1236.40	1142.81	1144.81	1118.15	1148.44
2030	1592.20	1592.96	1590.58	1452.61	1459.00	1422.02	1458.92
GHG emissions, Million tones.							
2010	334.31	334.40	334.30	304.76	305.95	301.56	305.48
2015	460.76	459.06	459.42	350.42	352.74	343.95	352.21
2020	585.02	594.14	594.18	384.76	389.20	379.30	387.42
2025	715.62	742.05	769.50	421.90	419.97	428.10	423.00
2030	924.84	965.98	994.71	551.94	547.47	569.70	545.30
Primary Energy Consumption, Mtoe.							
2010	121.00	121.04	121.01	112.07	112.41	111.28	112.27
2015	162.44	162.01	162.09	131.87	132.56	130.14	133.96
2020	206.67	206.44	206.89	152.18	151.92	148.16	155.28
2025	251.64	253.67	257.95	173.44	171.12	167.40	179.34
2030	312.65	318.93	322.67	213.46	212.28	210.79	220.66
Final Energy, Mtoe.							
2010	93.81	93.82	93.79	86.80	87.01	86.28	86.98
2015	123.00	122.89	122.80	103.40	103.87	102.25	104.03
2020	156.10	155.07	155.00	122.23	121.72	118.75	123.33
2025	192.71	190.74	190.06	143.51	142.24	135.03	145.26
2030	234.52	234.01	232.24	173.17	173.96	165.76	175.84
Electricity, TWh.							
2010	240.71	241.14	241.01	231.23	231.97	230.35	231.06
2015	358.29	356.11	357.39	299.98	301.76	297.26	303.76
2020	514.16	488.47	494.35	407.06	390.02	373.81	414.73
2025	654.08	618.35	614.33	517.79	490.86	437.65	532.28
2030	784.16	771.26	760.92	606.67	591.16	539.13	620.45

Table 5.8: Primary Energy Consumption, Mtoe.

	Coal	Lignite	Wood	Renew.	Nuclear	Petrol.	N. Gas	Hydro.
BC.								
2010	20.72	15.27	5.59	0.38		41.62	32.80	4.60
2020	40.33	35.91	5.59	1.52	3.25	60.65	49.11	10.32
2030	90.25	56.69	5.59	4.33	9.75	89.72	45.19	11.13
OP.								
2010	20.71	15.27	5.59	0.38		41.61	32.87	4.60
2020	39.57	38.28	5.59	1.62	0.00	60.94	49.48	10.96
2030	101.57	56.67	5.59	4.33	4.40	89.82	45.41	11.13
NoN.								
2010	20.69	15.27	5.59	0.38		41.62	32.85	4.60
2020	42.52	35.91	5.59	1.62		60.90	49.39	10.95
2030	109.16	56.69	5.59	4.33		90.12	45.64	11.13
BCq30.								
2010	15.74	14.39	5.59	0.38		39.59	31.77	4.60
2020	15.10	17.08	5.59	2.14	3.25	52.36	46.35	10.32
2030	30.72	29.44	5.59	7.53	9.75	72.00	47.29	11.13
OPq30.								
2010	15.84	14.52	5.59	0.38		39.65	31.81	4.60
2020	15.25	17.59	5.59	2.44	0.58	52.78	46.57	11.13
2030	28.08	30.10	5.59	7.53	9.75	72.69	47.41	11.13
NoNq30.								
2010	15.40	13.96	5.59	0.38		39.41	31.93	4.60
2020	14.08	16.63	5.59	2.05		52.04	46.76	11.00
2030	34.29	28.01	5.59	7.53		71.09	53.14	11.13
BCccsQ30.								
2010	15.92	14.39	5.59	0.38		39.68	31.71	4.60
2020	16.06	19.03	5.59	2.16	3.25	52.64	46.23	10.32
2030	32.47	33.47	5.59	7.53	9.75	72.53	48.19	11.13
BC-high.								
2010	20.74	15.27	5.59	0.38		41.24	32.69	4.60
2020	39.50	36.20	5.59	1.52	3.25	58.94	48.75	10.32
2030	86.29	56.72	5.59	4.33	9.75	84.92	44.15	11.13
BC-low.								
2010	20.66	15.27	5.59	0.38		41.64	34.73	4.60
2020	44.02	35.15	5.59	1.48	3.25	61.89	54.39	10.32
2030	105.37	56.69	5.59	4.33	9.75	94.98	52.83	11.13

Table 5.9: Electricity Production, TWh.

	Regular							CCS		
	Coal	Lign.	Renew.	Nuclear	Petrol.	N. Gas	Hydro.	Coal	Lign.	N. Gas
BC										
2010	20.08	43.96	4.46		4.33	114.33	53.52			
2020	58.67	99.54	17.62	37.79	1.86	178.73	119.95			
2030	253.02	120.00	50.36	113.37	3.25	114.77	129.39			
OP										
2010	20.08	43.96	4.46		4.33	114.76	53.52			
2020	51.92	108.93	18.89	0.00	1.86	179.47	127.39			
2030	301.60	120.00	50.36	51.17	3.25	115.48	129.39			
NoN										
2010	20.08	43.96	4.46		4.33	114.63	53.52			
2020	67.52	99.48	18.89		1.86	179.25	127.33			
2030	342.62	120.00	50.36		3.25	115.29	129.39			
BCq30										
2010	15.50	40.61	4.46		4.33	112.79	53.52			
2020	18.23	28.28	24.93	37.79	1.86	176.03	119.95			
2030	77.16	41.43	87.58	113.37	3.25	154.50	129.39			
OPq30										
2010	15.58	41.14	4.46		4.33	112.92	53.52			
2020	17.46	29.94	28.38	6.73	1.86	176.26	129.39			
2030	61.32	42.28	87.58	113.37	3.25	153.97	129.39			
NoNq30										
2010	15.09	38.95	4.46		4.33	113.98	53.52			
2020	15.53	26.55	23.84		1.86	178.11	127.90			
2030	93.61	38.94	87.58		3.25	186.35	129.39			
BCccsQ30										
2010	15.86	40.61	4.46		4.33	112.25	53.52			
2020	17.91	28.19	25.13	37.79	1.86	175.09	119.95	3.28	5.52	0.00
2030	69.54	34.03	87.58	113.37	3.25	142.94	129.39	13.14	13.26	13.95
BC-high										
2010	20.08	43.96	4.46		4.33	113.86	53.52			
2020	56.23	100.55	17.63	37.79	1.86	177.90	119.95			
2030	240.51	120.00	50.36	113.37	3.25	113.93	129.39			
BC-low										
2010	20.08	43.96	4.46		4.33	121.95	53.52			
2020	65.90	96.65	17.19	37.79	1.86	192.02	119.95			
2030	296.37	120.00	50.36	113.37	3.25	129.00	129.39			

CHAPTER 6

CONCLUSION

A multi-sector energy-economy-environment model for Turkey has been formulated and implemented in this study in which the evolution of energy balances as well as macroeconomic implications of energy decisions are investigated in detail under several scenarios. In addition to its ability to represent energy-economy interactions, the model is extended to assess the impacts of each scenario on environmental variables, specifically GHG emissions.

The aims of this effort are twofold; firstly, integrating sectoral detail and energy specifics into a macroeconomic model formulated as an activity analysis/optimization problem, and secondly evaluating the impacts of policies such as the implementation of a nuclear power programme, setting quotas on GHG emissions and the use of abatement technologies in the case of Turkey. It should be noted that the contribution of this study is methodological. Even so, we pay the highest attention for our scenarios to address current energy issues in the country as well as employing realistic cost and capacity figures. Nonetheless, the scenarios are not meant to address all aspects of the energy problem in Turkey and serve only to demonstrate the capabilities of the model while providing insight for some energy issues in the country.

The model has been calibrated, implemented and validated so far as it is capable of producing reference trajectories in agreement with the recent performance of the Turkish economy. It is flexible enough to adapt to varying conditions and scenarios. Its main strength is that it can address and evaluate detailed and explicit energy alternatives and decisions in terms of the macroeconomic, multi-sectoral and foreign trade implications of those decisions since the activity analysis format is flexible and affords representation and assessment of detailed policy options. As such, the model avoids as much as possible the downside of both bottom-up and top-down approaches, representing a hybrid that reflects all three dimensions of microeconomic realism, macroeconomic completeness and technological explicitness. The solutions computed by the model can serve as a benchmark in designing regulatory instruments such as caps, quotas, taxes or subsidies.

The most notable finding in our analysis for Turkey is that environmental concerns weigh heavily on GDP and on energy use given existing technological options. As the model tries to restrict emissions, energy has to be substituted more and more by other factors but not nearly enough as to sustain present growth rates. Although events can turn out differently in practice and slower growth can somehow be avoided to a degree, model calculations underscore the magnitude and the opportunity cost associated with not developing environment friendly energy alternatives. What can be inferred from the calculations is that it is too optimistic to expect to sustain both economic growth and a clean environment without a strong commitment to policy change and unless vigorous abatement policies are implemented. The scenario comprising the CCS technology illustrates one such policy. Under this scenario the model has the option to choose between conventional power generation and power generation coupled with carbon-capture-and-storage schemes. Calculations indicate that the availability of this option returns higher levels of GDP compared to abatement schemes relying on fuel substitution only.

Although the model is capable of assessing the feasibility of new technologies, such as plants coupled with CCS technology or nuclear plants, or policies such as implementing emission quotas, further work is needed to properly assess alternatives such as taxing the use of fuels, carbon taxes, taxing energy use in sectoral production or subsidizing abatement technologies and certain types of fuels. It should also be noted that our conclusions are based on assumptions some of which are quite strong. We assume that substitution possibilities in production are described through CES production functions in all sectors that allow different elasticities of substitution, whereas a unitary elasticity of substitution is assumed between capital and labor and among energy inputs. Production structure, however, may differ among sectors; for example there may be a complementary relationship between energy inputs and capital in some of the sectors as summarized by [59] in which several nesting structures of energy, capital and labor were investigated. Further research in this direction however would require comprehensive sectoral analysis in advance.

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APPENDIX A

GENERAL ENERGY BALANCE

Table A.1: Solid Fuels Balance, Original Units, 2009.

	Hard Coal	Lignite	Asphaltite	Sec. Coal	P. Coke	Wood	Plant & Animal W.
	kton	kton	kton	kton	kton	kton	kton
Primary Energy Supply	**23698**	**75641**	**1010**	**64**	**2684**	**11766**	**4862**
Domestic Production	2863	75577	1058			11766	4862
Import (+)	20364			274	2702		
Export (-)							
Bunker Sales							
Change in Stocks	471	64	-48	-211	-18		
Statistical Discrepancy							
Generation and Energy Sector	**-11440**	**-62969**	**-190**	**3437**		**-22**	**-258**
Power Plants	-6361	-62894	-190			-22	-258
Cooking Coal Firms	-4900			3437			
Oil Refinery							
Domestic Consumption and Loss	-179	-75					
Final Energy Consumption	**12258**	**12672**	**821**	**3501**	**2684**	**11743**	**4604**
Industrial Consumption	4918	6142	326	3500	2684		
Iron and Steel	928			3391			
Chemical-Petrochemical	72	279					
Petrochemical Feedstock							
Fertilizer							
Cement	2566	1565			2328		
Sugar	6	109		54			
Non-ferrous metal		152			18		
Other Industry	1346	4037	326	55	338		
Transportation							
Railway transportation							
Sea transportation							
Air transportation							
Pipelines							
Land transportation							
Other Sectors	7340	6530	494	1		11743	4604
Residential and Services	7337	6530	494	1		11743	4604
Agriculture	2						
Non-energy							

Table A.2: Non-Solid Fuels Balance, Original Units, 2009.

	Oil	Natural Gas	Hydroelectricity	Geothermal Electricity	Biomass	Wind	Electricity	Geothermal Heat	Solar
	kton	M Sm^3	GWh	GWh	kton	GWh	GWh	ktoe	ktoe
Primary Energy Supply	**29845**	**35800**	**35959**	**436**	**10**	**1495**	**-734**	**1250**	**429**
Domestic Production	2237	685	35959	436	10	1495		1250	429
Import (+)	33176	35856					812		
Export (-)	5889	709					1546		
Bunker Sales	637								
Change in Stocks	-407	-33							
Statistical Discrepancy	1365								
Generation and Energy Sector	**-1651**	**-21944**	**-35959**	**-436**		**-1495**	**156485**	**1056**	
Power Plants	-1225	-20483	-35959	-436		-1495	194813	1056	
Oil Refinery		-1002					-1143		
Domestic Consumption and Loss	743	-459					37185		
Final Energy Consumption	**28194**	**13856**			**10**		**155751**	**2306**	**429**
Industrial Consumption	3382	6015					69327	1056	129
Iron and Steel	9	776					16000	232	
Chemical-Petrochemical	52	324					4480		
Petrochemical Feedstock	1670								
Fertilizer	5	28					228		
Cement	31	22					5564		
Sugar	16	18					488		
Non-ferrous metal	3	469					1924		
Other Industry	1598	4379					40642	824	129
Transportation	14776	228			10		659		
Railway transportation	136						240		
Sea transportation	508								
Air transportation	1616								
Pipelines		188					313		
Land transportation	12516	40			10		107		
Other Sectors	5710	7614					85765	1250	300
Residential and Services	1492	7613					80886	964	300
Agriculture	4218	1					4879	286	
Non-energy	4326								

APPENDIX B

ENERGY DATA

This chapter is devoted to the data related to energy activities. Our assumptions and the base year energy balance revised along with these assumptions are given first. Next, domestic and foreign fuel costs, and the way of preprocessing these costs are presented. Finally, cost components of generating electricity as well as the procedure employed to calculate the cost of generating electricity is described in detail.

Before continuing with the assumptions and model data, it would be better to give some information about energy units and unit conversion factors as well as the calorific values of the main energy inputs. All energy related variables are expressed in terms of a unit energy measure (ktoe) in our model. Conversion factors for energy resources can be seen in Table B.1 and calorific values of the resources are tabulated in Table B.2. Note that, for each lignite type, average calorific values are calculated based on the calorific values and amount of reserves in the corresponding region, [50]. Calorific value of wood, on the other hand, is assumed to be 2800 kcal/kg as in [54], which is less than the general assumption of 3000 kcal/kg, since it is grouped with plant & animal waste in our model.

Table B.1: Conversion Factors for Energy.

	GWh	ktoe	kcal	GJ	MBtu
GWh	1	8.60E-02	8.60E+08	3.60E+03	3.41E+03
ktoe	1.16E+01	1	1.00E+10	4.19E+04	3.97E+04
kcal	1.16E-09	1.00E-10	1	4.19E-06	3.97E-06
GJ	2.78E-04	2.39E-05	2.39E+05	1	5.11E+05
MBtu	2.93E-04	2.52E-05	2.52E+05	1.96E-06	1

Table B.2: Calorific Values, kcal/kg.

Fuel	Calorific Value
Hard Coal	6450
$Lignite_1$	2450
$Lignite_2$	1700
$Lignite_3$	1100
Petroleum Products	10500
Natural Gas	9100
Wood	2800

B.1 ASSUMPTIONS AND BASE YEAR ENERGY BALANCE

We have made a number of assumptions in order to keep the model in manageable limits while maintaining the key features and dynamics of the Turkish energy sector. These assumptions, which were mainly shaped by the availability of the data, and modeling restrictions, are listed as follows.

- Total energy supply is distributed to domestic production and imports proportionally, that is, bunker sales, change in stocks and statistical discrepancy are distributed among domestic production and imports proportional to their amounts.
- Consumption of the resources in the refineries, for briquette production, in coke plants and own use & loss of these resources are grouped in a single ”other” variable for each resource. The ratio of these variables to the corresponding totals are calculated for each resource and these values are employed to reflect the impact of these ”other” variables in the model output. For example, it makes a sum of 10% of petroleum products which are either consumed in the refineries or for own use & loss, then the resulting total oil supply obtained from the model is increased by 10% to provide more precise projections.
- Secondary coal and asphaltite are included in hard coal data.
- Petro Coke is accounted as Petroleum Products.
- Geothermal heat and solar heat are ignored.
- Domestic natural gas is ignored.

- Wood and animal & plant waste are grouped.
- Cement, Chemical-Petrochemical, Fertilizer, Iron and Steel, Non-ferrous metal and Petrochemical Feedstock sectors are grouped under ”Energy-intensive Industry”.
- Non-energy, other energy and sugar sectors are accounted as ”Other Industry”.
- Domestic hard coal is assumed to be used only for sectoral consumption.
- Domestic petroleum products are assumed to be used only for sectoral consumption.
- Variables representing electricity generation denote the gross generation values, that is, losses are not taken into account which imply that the resulting final energy consumptions include losses.
- Base year (t_0) fuel consumptions in the power plants are divided by the generation volumes to estimate the corresponding conversion factors. For example:

  $$conv_{NaturalGas} = \frac{TotNG_{t_0} - \sum_{i=1}^{n} N_{it_0}}{ENGAS_{t_0}} \tag{B.1}$$

  Note that the sum of sectoral energy consumptions is subtracted from the total primary supply in order to obtain the amount of fuel used in the power plants.

Table B.3 shows the domestic and foreign components of primary energy supply for each energy source while Table B.4 shows the sectoral decomposition of the final energy demand. Table B.5, on the other hand, illustrates the composition of electricity generation by plant type.

B.2 FUEL COSTS

In this section, domestic fuel costs are given first. Then, imported fuel costs and their projections during the planning horizon are tabulated. Note that all cost parameters used in the model are given in 2003 prices.

Domestic energy costs are taken from Seyhan [54]. These costs are are tabulated in Table B.6 and are assumed to be unchanged during the planning horizon. Note that there also is a

Table B.3: Total Energy Supply, ktoe, 2003.

	Domestic Production	Imports	Total Supply
Natural Gas	510	18940	19450
Petroleum Products	2173	30953	33127
Solid: Total	16516	10609	27125
Hard Coal	1055	10609	11664
Lignite	9713		9713
Wood	5748		5748
Electricity: Total	3120	49	3169
Hydroelectricity	3038		3038
Wind	5		5
Geothermal Electricity	76		76
Electricity (International Trade)		49	49
Total Primary Energy	22319	60551	82871

Table B.4: Sectoral Decomposition of Final Energy Consumption, ktoe, 2003.

	Agriculture	IndHighEn	IndOther	Services	Transportation	Total
Hard Coal-Dom.		370	594	91		1055
Hard Coal-Imp.		2757	4425	676		7858
Lignite		503	1600	1248		3351
Wood		0	0	5748		5748
Natural Gas		1148	3212	3524	4	7888
Petroleum Prod.: Dom.	218	316	458	214	967	2173
Petroleum Prod.: Imp.	2554	3715	5378	2515	11348	25510
Electricity	411	1950	3821	5857	100	12139
Sectoral Total	3182	10760	19488	19874	12419	65723

Table B.5: Electricity Composition, GWh, 2003.

	Generation Amount, GWh
Hard Coal	8663.0
Lignite	23705.8
Natural Gas	63536.0
Petroleum Products	9196.2
Hydroelectricity	35329.5
Wind	61.4
Geothermal Electricity	88.6
Total	140580.5

washing cost component in addition to the extraction cost for lignite and hard coal since they are put through a cleaning process before the end-use.

Cost of imported fuels, on the other hand, are calculated in several steps as explained below:

Table B.6: Fuel Costs: Domestic Resources, [54].

	Extraction $/ton	Washing $/ton	Unit Cost $/ton	Calorific Value kcal/kg	Unit Cost Millions TL/ktoe
$Lignite_1$	15.52	5.93	21.45	2450	0.131
$Lignite_2$	24.94	5.93	30.87	1700	0.272
$Lignite_3$	8.88	5.93	14.81	1100	0.202
Hard Coal	128.27	4.20	132.47	6450	0.308
Crude Oil	32.92		32.92	10500	0.047
Wood			28.23	2800	0.151

Table B.7: Fuel Costs: Imports, [60].

	Crude Oil		Mining of coal, lignite and peat		Natural Gas	
	Payment Million $	Amount Millon tones	Payment Million $	Amount Millon tones	Payment Million $	Amount Billion m^3
2003	4776.54	24.03	929.25	16.17	2989.18	21188
2004	6091.54	23.92	1221.88	16.43	3274.26	22174
2005	8649.48	23.39	1579.30	17.02	5490.66	27028
2006	10706.47	23.79	1977.87	20.48	8513.55	30741
2007	11784.21	23.45	2569.73	22.95	9999.46	36450
2008	15638.92	21.83	3314.89	19.49	15469.60	37793
2009	6415.38	14.22	3055.02	20.37	9962.56	35856
2010	8696.32	15.42	3224.78		12742.83	

- Actual cost figures are calculated for years 2003-2010 based on the data published by TÜİK, [60]. Actual amounts of fuel imports and the payments for these fuels can be seen in Table B.7. Note that the crude oil imports are not consistent with the amounts in Tables A.2 and 3.3. The reason is that the values in Tables A.2 and 3.3 also include the processed crude oil (intermediate petroleum products). Another important observation from Table B.7 is the decline in crude oil imports after 2008 when refineries preferred to import intermediate petroleum products instead of crude oil due to the sharp increase in the oil prices.

- For imported fuels, projections in [55] are first converted into 2003 dollars. Note that the projections in [55] are given as OECD averages. When actual unit costs calculated from Table B.7 are compared to those averages, [55] and [61]-[66], costs figures for Turkey were found to be higher than the OECD averages. Hence, 1.05 for oil and natural gas and 1.50 for hard coal, are employed as adjustment coefficients based on these calculations.

- The projections for fuel prices are given for periods of five-years in [55]. We assume that the projections change linearly between every two consecutive projections and the interim projections are calculated accordingly.

- Tables B.8, B.9 and B.10 show the cost figures of crude oil, natural gas and hard coal imports, respectively. Note that, the cost figures for the period 2003-2010 for crude oil and 2003-2009 for natural gas and hard coal are calculated using the data in Table B.7 while the remaining figures are calculated based on the projections in [55] which are then adjusted using the adjustment coefficients mentioned in the previous item.

Table B.8: Price Projections: Crude Oil.

Year	$ /barrel	MTL/ktoe	Year	$ /barrel	Millions TL/ktoe
2003	29.02	0.298	2022	91.31	0.938
2004	36.22	0.372	2023	92.39	0.949
2005	50.87	0.523	2024	93.48	0.960
2006	59.98	0.616	2025	94.56	0.971
2007	65.12	0.669	2026	95.46	0.981
2008	89.37	0.918	2027	96.36	0.990
2009	56.49	0.580	2028	97.26	0.999
2010	69.49	0.714	2029	98.16	1.008
2011	63.40	0.651	2030	99.06	1.018
2012	67.90	0.698	2031	99.60	1.023
2013	72.40	0.744	2032	100.14	1.029
2014	76.91	0.790	2033	100.68	1.034
2015	81.41	0.836	2034	101.22	1.040
2016	82.96	0.852	2035	101.76	1.045
2017	84.51	0.868	2036	101.76	1.045
2018	86.05	0.884	2037	101.76	1.045
2019	87.60	0.900	2038	101.76	1.045
2020	89.15	0.916	2039	101.76	1.045
2021	90.23	0.927	2040	101.76	1.045

B.3 COST OF GENERATING ELECTRICITY

Electricity generation has three main cost components which are fuel costs, operation & maintenance costs and investment costs. We have already summarized the fuel costs in the previous section. In this section, operation & maintenance and investment costs will be presented for each production technology.

Table B.9: Price Projections: Natural Gas.

Year	$ /MBtu	MTL/ktoe		$ /MBtu	10^{12} TL/ktoe
2003	3.91	0.233	2022	10.70	0.637
2004	3.98	0.237	2023	10.82	0.644
2005	5.30	0.315	2024	10.95	0.652
2006	7.00	0.417	2025	11.08	0.659
2007	6.74	0.401	2026	11.18	0.666
2008	9.69	0.577	2027	11.29	0.672
2009	6.60	0.393	2028	11.40	0.679
2010	7.14	0.425	2029	11.51	0.685
2011	7.62	0.454	2030	11.62	0.691
2012	8.10	0.482	2031	11.69	0.696
2013	8.59	0.511	2032	11.76	0.700
2014	9.07	0.540	2033	11.83	0.704
2015	9.55	0.568	2034	11.91	0.709
2016	9.73	0.579	2035	11.98	0.713
2017	9.91	0.590	2036	11.98	0.713
2018	10.09	0.600	2037	11.98	0.713
2019	10.27	0.611	2038	11.98	0.713
2020	10.45	0.622	2039	11.98	0.713
2021	10.57	0.629	2040	11.98	0.713

Table B.10: Price Projections: Hard Coal.

Year	$ /ton	MTL/ktoe		$ /ton	10^{12} TL/ktoe
2003	57.47	0.134	2022	132.07	0.307
2004	72.44	0.168	2023	132.69	0.309
2005	87.40	0.203	2024	133.30	0.310
2006	88.17	0.205	2025	133.92	0.311
2007	99.38	0.231	2026	134.31	0.312
2008	145.36	0.338	2027	134.69	0.313
2009	128.65	0.299	2028	135.08	0.314
2010	125.26	0.291	2029	135.47	0.315
2011	125.35	0.292	2030	135.85	0.316
2012	125.43	0.292	2031	136.08	0.316
2013	125.52	0.292	2032	136.31	0.317
2014	125.60	0.292	2033	136.55	0.318
2015	125.69	0.292	2034	136.78	0.318
2016	126.72	0.295	2035	137.01	0.319
2017	127.75	0.297	2036	137.01	0.319
2018	128.78	0.299	2037	137.01	0.319
2019	129.81	0.302	2038	137.01	0.319
2020	130.83	0.304	2039	137.01	0.319
2021	131.45	0.306	2040	137.01	0.319

Operation & maintenance costs given in [54] are employed in our model with the following revisions.

Table B.11: Operation & Maintenance Cost for Generating Electricity, [54].

	$/KWh	Millions TL/ktoe
Hard Coal	0.0084	0.146
Lignite	0.0133	0.231
Fuel Oil	0.0023	0.039
Diesel Oil	0.0068	0.118
Natural Gas	0.0014	0.025
Wind	0.0042	0.072
Geothermal	0.0226	0.394
Hydro-Dam	0.0011	0.020
Hydro-River	0.0009	0.016
Nuclear	0.0132	0.230

- The fuel cost for nuclear plants is revised as 0.115 Millions TL/ktoe according to the document published by World Nuclear Association, [67].
- Solar electricity operation & maintenance cost, 0.252 Millions TL/ktoe, is calculated as 2% of the unit investment cost, [68].
- Since power plants firing fuel or and diesel oil are not distinguished in our model, a unique value is calculated for petroleum products power plants. This value, 0.045 Millions TL/ktoe, is determined based on the installed capacities of diesel oil and fuel oil plants.

The resulting cost figures can be seen in Table B.11.

Although there exists a number of publications which tabulate investment costs for electricity generation technologies, these costs considerably vary from country to country. That is why we refer to the cost figures reported in [54]. These values can be seen in Table B.12.

The investment cost per kWh, cpk, can be calculated using the following equation:

$$cpk = \frac{IC \cdot \delta}{[1 - (1 + \delta)^{PL}] \cdot PF \cdot 8760} \tag{B.2}$$

or equivalently

Table B.12: Investment Costs of Power Plants.

	Investment Cost $\$/kW$				Cost per kwh and ktoe	
	Fixed	Variable	Plant Life	Plant Factor	c/kwh	MTL/ktoe
Lignite-1	2056	1390	30	0.75	2.262	0.394
Lignite-2	2056	1390	30	0.75	2.262	0.394
Lignite-3	2056	1390	30	0.75	2.262	0.394
Hard Coal	58679	1026	30	0.75	1.786	0.311
Natural Gas	72537	502	25	0.80	1.265	0.221
Petroleum Products	1340	-	30	0.75	2.164	0.377
Wind	1250	-	25	0.35	4.492	0.783
Geothermal	2500	-	30	0.70	4.325	0.754
Hydro-Dam	*	*	40	0.40	3.532	0.616
Hydro-River	1207		40	0.50	2.818	0.492
Solar**	2000		25	0.20	12.576	2.194
Nuclear	4167		40	0.90	5.404	0.943

* Cost of dams are calculated based on the data for each individual project, [54].

** Investment cost of solar electricity is assigned according to [68].

$$cpk = \frac{IC}{\sum_{t=1}^{PL} \frac{8760 \cdot PF}{(1+\delta)^t}} \tag{B.3}$$

where IC, PL and PF denote the investment cost per kW, plant life and plant factor, respectively. δ stands for the annual discount rate and 8760 is the total hours in a year (24 times 365). Equation B.2 is derived from Equation B.4 where EAP denotes the equal annual payments satisfying the condition $\sum_{t=1}^{PL} \frac{EAP}{(1+\delta)^t} = IC$.

$$cpk = \frac{EAP}{8760 \cdot PF}. \tag{B.4}$$

Following procedure is employed to calculate the cpk values of the power plants with a variable investment cost, i.e., natural gas, lignite and hard coal power plants.

- Total investment costs for each individual plant is calculated using the formula $IC = FixC + VarC \cdot InsCap$ where $FixC$, $VarC$ and $InsCap$ denote the fixed and variable investment costs and installed capacity, respectively.

- IC value obtained in the first step is substituted in Equation B.2 to calculate the cpk value for each individual plant.

- Weighted average of cpk values are then calculated based on the cpk values and installed capacities of the individual plants.

Finally Table presents the values of τ_{qt}^{fuel} and τ_{qt}^{inv} which denote the shares of foreign components in fuel and investment costs, respectively.

Table B.13: Parameters: τ_{qt}^{fuel} and τ_{qt}^{inv}.

	τ_{qt}^{fuel}	τ_{qt}^{inv}
Hydro Dam	NA	0.50
Hydro River	NA	0.75
$Lignite_1$	0.00	0.75
$Lignite_2$	0.00	0.75
$Lignite_3$	0.00	0.75
Imported Coal	1.00	0.75
Domestic Coal	0.00	NA
Imported Petroleum Products	1.00	0.75
Domestic Petroleum Products	0.00	NA
Natural Gas	1.00	0.75
Wind	NA	0.75
Geothermal	NA	0.75
Solar	NA	0.75
Nuclear	1.00	1.00
Wood	0.00	NA

APPENDIX C

BASE YEAR MACROECONOMIC DATA

C.1 AN OVERVIEW OF THE TURKISH ECONOMY

Turkish economy has shown a remarkable development after the 2001 economic crisis. An impressive recovery has been created with an economic growth of more than 7% on average during the period 2002-2010, which positions Turkey in the category of the highest growing economies together with India, China, Korea, Singapore, Brazil and Taiwan. In this period, the Central Bank's independence was established and banking sector was restructured as a result of new banking law and regulations. Another important success has been achieved in pulling the inflation rate from 70% to one-digits.

By the end of 2010, Turkish economy is one of the world's 20 largest economies, with a population of 73.7 million and GDP of 1,105 billion TL ($735 billion). Despite all of these positive indicators, the fact that the growth of the economy is mostly subject to the foreign capital inflows makes the economy quite volatile, [69]. Specifically, with the rapid rise of the import bill, the deficit in the current account has reached $63.4 billion (8.3% of the GDP) by May 2011, which is quite high compared to developed economies.

Table C.1 shows the GDP, Imports and Exports for the period 2002-2010 in both constant and current prices. Figure C.1, which displays imports, exports and balance of foreign trade, indicates that the Turkish Economy has been integrated into the world economy in the recent two decades, [77]. Despite the fact that GDP has increased spectacularly after 2001, Turkey has still in the lower end in respect of GDP per capita as seen in Figure C.2. Additionally, Figure C.3 displays the development of sectoral structure of the economy. This figure implies that, Turkish economy has been moving from an agricultural economy to an industrialized economy consistently which brings crucial economic challenges as well as social problems.

Table C.1: GDP, Exports and Imports: Billions TL, [60].

	in 1998 prices				in current prices				
Year	GDP	Growth Rate	Exports	Imports	GDP	Exports	% of GDP	Imports	% of GDP
2002	72.5		17.2	15.1	350.5	88.4	25.2%	82.7	23.6%
2003	76.3	5.3%	18.4	18.7	454.8	104.6	23.0%	109.3	24.0%
2004	83.5	9.4%	20.5	22.5	559.0	131.7	23.6%	146.4	26.2%
2005	90.5	8.4%	22.1	25.3	648.9	141.8	21.9%	164.5	25.4%
2006	96.7	6.9%	23.6	27.0	758.4	171.9	22.7%	209.2	27.6%
2007	101.3	4.7%	25.3	29.9	843.2	188.2	22.3%	231.7	27.5%
2008	101.9	0.7%	26.0	28.7	950.5	227.3	23.9%	269.4	28.3%
2009	97.0	-4.8%	24.7	24.6	952.6	222.1	23.3%	232.6	24.4%
2010	105.7	8.9%	25.5	29.7	1105.1	233.1	21.1%	294.0	26.6%

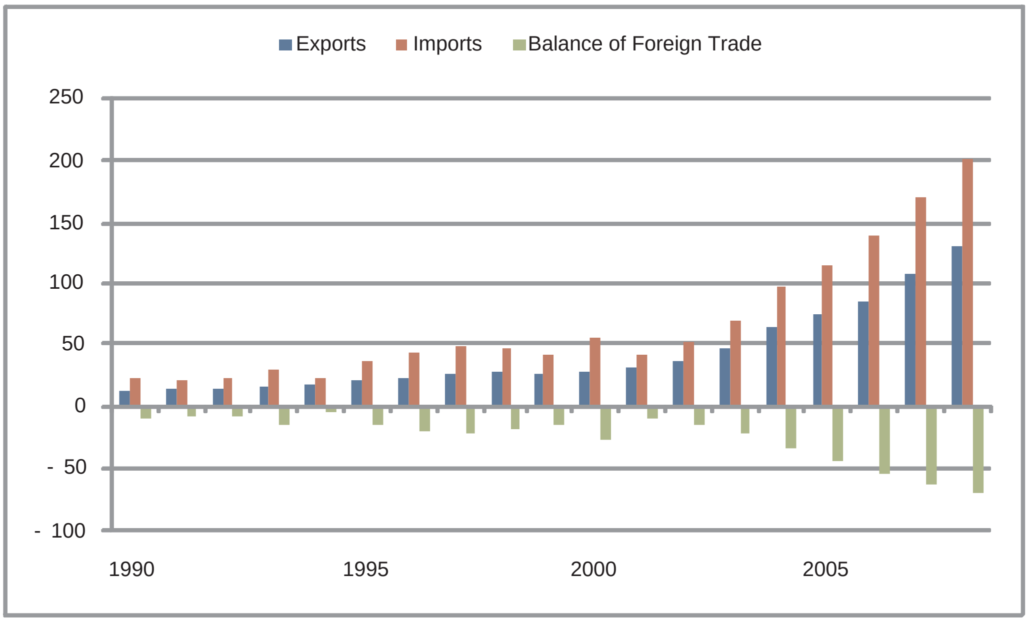

Figure C.1: Exports, Imports and Balance of Foreign Trade, Billions $, [60].

C.2 MACROECONOMIC DATA

In our model, economic activity is assumed to take place in five sectors: *Agriculture*, *Industry: Energy-intensive*, *Industry: Other*, *Services* and *Transportation*. Note that energy is not accounted as one of these sectors since our model treats it as a separate sector with its own module. Input-Output Table of 2002, published by TÜİK, [60], is used in decomposing

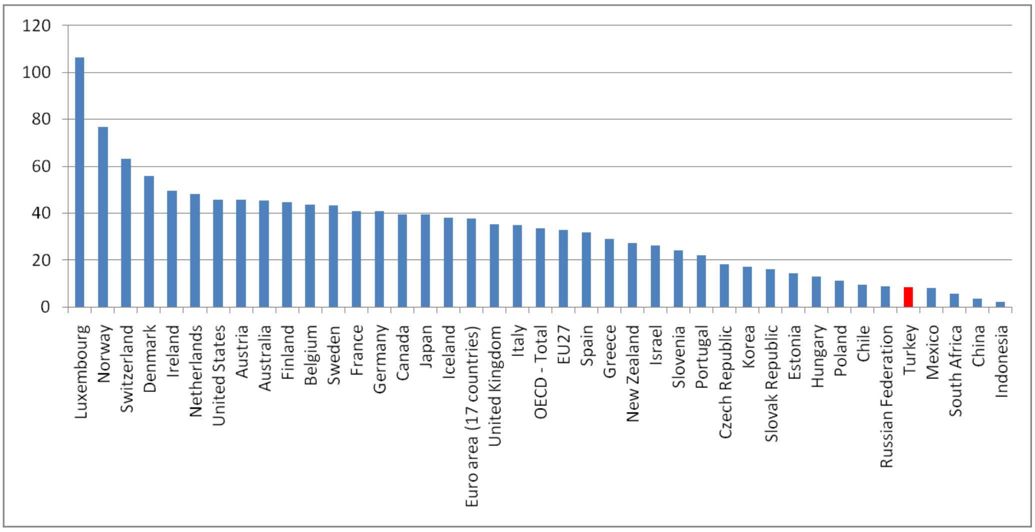

Figure C.2: Per head, US $, Current Prices, Current Exchange Rates: 2008, [70]

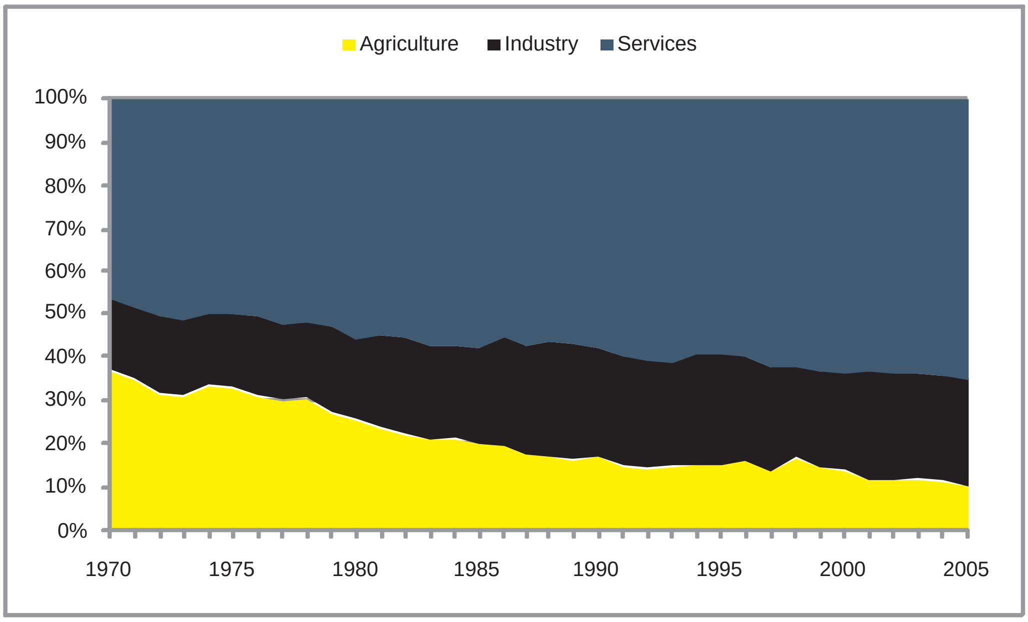

Figure C.3: Development of Sectoral Shares of the GNP.

macroeconomic variables into sectoral components. These tables consist of 59 subsectors (see Table C.7 at the end of the appendix for the sector headings). Table C.7 also shows how these subsectors are classified into aforementioned five sectors and energy sector.

Input-Output tables are essential to understand the dynamics of an economy since they tabulate the inter-industry flow of goods and services, i.e., they show technological relations among the sectors. These tables are mostly used in input-output analysis and CGE models in which SAMs are constructed based on I-O Tables. I-O Tables are derived from Supply and Use Tables. Supply Tables show the output by product and by the supplier sector. Use Tables, on the other hand, show the use of output by product and by type of use, i.e., intermediate consumption, final consumption, capital formation and exports, [60].

Table C.2 shows the domestic and foreign components of sectoral consumptions in the base year. These values are determined by distributing total domestic and imported consumption in 2003, proportional to the sectoral consumptions in the I-O Table.

Table C.2: Base Year Data: Consumption, 2003 prices, Billions TL.

	Imports	Domestic	Total
Agriculture	0.32	28.84	29.17
Industry: Energy-intensive	2.47	6.50	8.97
Industry: Other	6.61	85.82	92.43
Services	1.49	200.37	201.86
Transportation	0.13	36.34	36.47
Total	11.02	357.87	368.90

Table C.3 displays sectoral exports and imports used in our model. These values are determined in the same way as the sectoral consumptions were calculated. Note that exports does not include ”Final Consumption Expenditure of Non-Resident Households on the Economic Territory” as explained in Section 4.1. Imports, on the other hand, does not include energy imports since energy imports are treated separately.

Table C.3: Base Year Data: Imports and Exports, 2003 prices, Billions TL.

	Exports	Imports
Agriculture	2.9	3.3
Industry: Energy-intensive	9.4	29.3
Industry: Other	42.4	49.9
Services	16.1	3.9
Transportation	7.9	4.0
Total	78.7	90.3

Inter-sectoral flows of intermediate and investment goods are displayed in Tables C.4 and C.5, respectively. Inter-sectoral flows of intermediates are determined by distributing the base year totals of domestic and imported intermediate goods, proportional to the corresponding amounts in the I-O table. On the other hand, no data is available about how the inter-sectoral flows of investment goods are realized. Total investment demand for the goods of each sector is then distributed among all sectors based on the sectoral capital stocks. Knowing that the new capital is formed by the investments; employing this procedure makes sense since higher the capital stock of a sector, higher the investment goods demanded by the corresponding sector in the resulting matrix.

Table C.4: Base Year Data: Inter-sectoral Flows of Intermediate Goods, 2003 prices, Millions TL.

	Agriculture	Industry: Energy-intensive	Industry: Other	Services	Transportation
Domestic					
Agriculture	10393.88	389.33	26404.71	3524.12	31.38
Industry: Energy-intensive	1975.39	11467.15	16462.38	14808.69	459.03
Industry: Other	3464.73	6395.15	61766.94	28454.08	3542.49
Services	5042.19	8053.01	31686.64	80374.22	17490.24
Transportation	1132.86	2816.38	10190.85	11610.73	6312.38
Imports					
Agriculture	303.16	171.41	2296.00	169.51	0.03
Industry: Energy-intensive	646.57	7804.93	14062.15	4270.24	23.57
Industry: Other	355.54	1336.77	16424.76	6094.80	1252.15
Services	113.94	212.35	390.09	1456.26	222.89
Transportation	13.21	63.74	148.89	2290.05	1327.63
Total					
Agriculture	10697.04	560.74	28700.71	3693.63	31.41
Industry: Energy-intensive	2621.97	19272.08	30524.54	19078.93	482.60
Industry: Other	3820.27	7731.92	78191.69	34548.88	4794.64
Services	5156.13	8265.36	32076.72	81830.47	17713.13
Transportation	1146.07	2880.12	10339.73	13900.77	7640.01

Sectoral capital stocks are determined in several steps as summarized below:

- Share of each sector is calculated based on the data given in [71].
- Capital/output ratio is assumed to be 3 as it is in [44] and [45]. Then, GDP in year 2003 is multiplied by this ratio to determine the total capital stock.
- Total capital stock obtained in the previous step is multiplied by the sectoral shares attained in the first step to determine the sectoral capital stocks.

Finally, Table C.6 summarizes the base year macroeconomic data used in our model. Note that domestic and foreign energy costs in Table C.6 are calculated through Equations 4.56 and 4.57, and sectoral VAs are determined through Equation 4.5.

Table C.5: Base Year Data: Inter-sectoral Flows of Investment Goods, 2003 prices, Millions TL.

	Agriculture	Industry: Energy-intensive	Industry: Other	Services	Transportation
Domestic					
Agriculture	0.65	0.56	2.29	7.44	2.99
Industry: Energy-intensive	0.00	0.00	0.00	0.00	0.00
Industry: Other	824.95	710.64	2929.43	9520.85	3825.90
Services	1.42	1.22	5.04	16.39	6.59
Transportation	0.00	0.00	0.00	0.00	0.00
Imports					
Agriculture	0.82	0.70	2.90	9.42	3.79
Industry: Energy-intensive	0.07	0.06	0.23	0.75	0.30
Industry: Other	663.57	571.62	2356.36	7658.32	3077.46
Services	1992.53	1716.42	7075.52	22995.92	9240.78
Transportation	99.23	85.48	352.38	1145.27	460.22
Total					
Agriculture	1.46	1.26	5.19	16.86	6.78
Industry: Energy-intensive	0.07	0.06	0.23	0.75	0.30
Industry: Other	1488.52	1282.26	5285.79	17179.17	6903.35
Services	1993.95	1717.64	7080.57	23012.31	9247.37
Transportation	99.23	85.48	352.38	1145.27	460.22

Table C.6: Sectoral Macroeconomic Data: 2003 prices, Millions TL.

	Agri.	Industry: Ener. Inten.	Industry: Other	Services	Trans.	Total
Y	72488	61104	246196	402131	78440	860360
GDP						438013
VA	47965	18966	60071	241884	44275	413160
K	60860	52426	216115	702388	282251	1314039
EC^D	119	727	1475	2662	72	5055
EC^F	963	2700	4817	4533	3432	16445
C^D	28841	6502	85820	200371	36339	357872
C^F	324	2473	6606	1492	127	11023
X	2887	9428	42425	16092	7896	78728
M	3278	29281	49882	3919	3970	90330
NRH						24853

Table C.7: Classification of Sectors.

Sector	Code	Subsector
Agriculture	1	Agriculture, hunting and related service activities
	2	Forestry, logging and related service activities
	5	Fishing, operating of fish hatcheries and fish farms; service activities incidental to fishing
Energy	10	Mining of coal and lignite; extraction of peat
	11	Extraction of crude petroleum and natural gas; service activities incidental to oil and gas extraction excluding surveying
	12	Mining of uranium and thorium ores
	23	Manufacture of coke, refined petroleum products and nuclear fuels
	40	Electricity, gas, steam and hot water supply
Industry:	13	Mining of metal ores
Other	14	Other mining and quarrying
	15	Manufacture of food products and beverages
	16	Manufacture of tobacco products
	17	Manufacture of textiles
	18	Manufacture of wearing apparel; dressing and dyeing of fur
	19	Tanning and dressing of leather; manufacture of luggage, handbags, saddlery, harness and footwear
	20	Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials
	21	Manufacture of pulp, paper and paper products
	22	Publishing, printing and reproduction of recorded media
	25	Manufacture of rubber and plastic products
	28	Manufacture of fabricated metal products, except machinery and equipment
	29	Manufacture of machinery and equipment n.e.c.
	30	Manufacture of office machinery and computers
	31	Manufacture of electrical machinery and apparatus n.e.c.
	32	Manufacture of radio, television and communication equipment and apparatus
	33	Manufacture of medical, precision and optical instruments, watches and clocks
	34	Manufacture of motor vehicles, trailers and semi-trailers
	35	Manufacture of other transport equipment
	36	Manufacture of furniture; manufacturing n.e.c.
	37	Recycling
	50	Sale, maintenance and repair of motor vehicles and motorcycles; retail sale services of automotive fuel
Industry:	24	Manufacture of chemicals and chemical products
Energy	26	Manufacture of other non-metallic mineral products
Intensive	27	Manufacture of basic metals

Table C.7 Continued.

Sector	Code	Subsector
Services	41	Collection, purification and distribution of water
	45	Construction
	51	Wholesale trade and commission trade, except of motor vehicles and motorcycles
	52	Retail trade, except of motor vehicles and motorcycles; repair of personal and household goods
	55	Hotels and restaurants
	63	Supporting and auxiliary transport activities; activities of travel agencies
	64	Post and telecommunications
	65	Financial intermediation, except insurance and pension funding
	66	Insurance and pension funding, except compulsory social security
	67	Activities auxiliary to financial intermediation
	70	Real estate activities
	71	Renting of machinery and equipment without operator and of personal and household goods
	72	Computer and related activities
	73	Research and development
	74	Other business activities
	75	Public administration and defence; compulsory social security
	80	Education
	85	Health and social work
	90	Sewage and refuse disposal, sanitation and similar activities
	91	Activities of membership organization n.e.c.
	92	Recreational, cultural and sporting activities
	93	Other service activities
	95	Private households with employed persons
Transportation	60	Land transport; transport via pipelines
	61	Water transport
	62	Air transport

APPENDIX D

MODEL CALIBRATION

Calibration of the model parameters has a crucial role in obtaining consistent and reliable results. Some of the parameters in our model are assigned to benchmark values from the literature and most of them are calibrated using the base year data. In this chapter, we will first describe the calibration procedure for the gross output functions and the objective function. Next we will briefly summarize the determination of parameters used for modeling inter-sectoral flows, foreign trade, capital accumulation and annual changes in energy supply.

D.1 CALIBRATION PROCEDURE: GROSS OUTPUT FUNCTIONS AND OBJECTIVE FUNCTION

Recall that the sectoral gross output function, in its general form, is as follows:

$$Y_i = \frac{\gamma_i[\alpha_i(K_i^{sk_i}L_i^{sl_i})^{\rho_i} + (1-\alpha_i)(E_i^{se_i}P_i^{sp_i}N_i^{sng_i}S_i^{ss_i})^{\rho_i}]^{(\frac{1}{\rho_i})}}{(1 - IntToY_i)} \qquad \forall i$$

Without loss of generality and for the sake of simplicity let $a_iA_i^{\rho_i} = \gamma_i^{\rho_i}\alpha_i(K_i^{sk_i}L_i^{sl_i})^{\rho_i}$, $b_iB_i^{\rho_i} = \gamma_i^{\rho_i}(1-\alpha_i)(E_i^{se_i}P_i^{sp_i}N_i^{sng_i}S_i^{ss_i})^{\rho_i}$ and $C_i = (1 - IntToY_i)Y_i$. Then, the gross output function can be rewritten in its simplest form of a CES function as follows:

$$C_i = [a_iA_i^{\rho_i} + b_iB_i^{\rho_i}]^{(\frac{1}{\rho_i})} \qquad \forall i \qquad \text{(D.1)}$$

Then, each sector faces with its own problem as defined below:

$$Maximize\ \pi_i = p_{C_i}C_i - p_{A_i}A - p_B B_i$$

$$st$$

$$C_i = [a_i A_i^{\rho_i} + b_i B_i^{\rho_i}]^{(\frac{1}{\rho_i})}$$

where π_i is the profit in sector i, p_{C_i}, p_{A_i} and p_{B_i} are the price of final output, and prices of factor inputs of A and B, respectively.

An equivalent problem can be expressed as below:

$$Maximize\ L_i(A_i, B_i, \Lambda_i) = p_{C_i}C_i - p_{A_i}A_i - p_{B_i}B_i - \Lambda_i[C_i - a_i A_i^{\rho_i} + b_i B_i^{\rho_i}]^{(\frac{1}{\rho_i})}$$

where Λ_i is called the Lagrangean multiplier.

The optimal solution of $L_i(A_i, B_i, \Lambda_i)$, where $A_i \geq 0$ and $B_i \geq 0$, should satisfy the following conditions:

$$\frac{\partial L_i}{\partial \Lambda_i} = 0, \quad \frac{\partial L_i}{\partial A_i} = 0, \quad \frac{\partial L_i}{\partial B_i} = 0 \tag{D.2}$$

The first condition is obvious which results in Equation D.1. The second condition is as follows:

$$\frac{\partial L_i}{\partial A_i} = -p_{A_i} + \Lambda_i \cdot a_i \cdot \rho_i \cdot A_i^{\rho-1} \cdot \frac{1}{\rho_i} \cdot [a_i A_i^{\rho_i} + b_i B_i^{\rho_i}]^{(\frac{1}{\rho_i}-1)} = 0 \tag{D.3}$$

After rearranging the terms in Equation D.3 we come up with:

$$\frac{\partial L_i}{\partial A_i} \quad = -p_{A_i} + \Lambda_i \cdot a_i \cdot A_i^{\rho-1} \cdot C_i^{(1-\rho_i)} = 0 \tag{D.4}$$

which implies that

$$p_{A_i} \quad = \Lambda_i \cdot a_i \cdot A_i^{\rho_i-1} \cdot C_i^{(1-\rho_i)} \tag{D.5}$$

Similarly,

$$p_{B_i} \quad = \Lambda_i \cdot b_i \cdot B_i^{\rho_i-1} \cdot C_i^{(1-\rho_i)} \tag{D.6}$$

Equations D.5 and D.6 indicate the following equation:

$$\frac{p_{A_i}}{p_{B_i}} = \frac{a_i \cdot A_i^{\rho_i - 1}}{b_i \cdot B_i^{\rho_i - 1}} \tag{D.7}$$

Then, one can obtain the values of a_i and b_i only if there exist benchmark values for all other variables and parameters.

We assume a price of unity for the first aggregate in the production function (capital-labor aggregate), and calculate the average cost for the second aggregate (average cost of energy in the base year). Share parameters for energy inputs, se_i, sp_i, sng_i and ss_i, are calibrated by calculating corresponding cost shares as seen in the following equations.

$$se_i = \frac{p_{Elec,t_0} \cdot E_{it_0}}{EC_{it_0}} \tag{D.8}$$

$$sng_i = \frac{cf_{NaturalGas,t_0} \cdot N_{it_0}}{EC_{it_0}} \tag{D.9}$$

$$ss_i = \frac{\sum_{q \in setS} \cdot cf_{q,t_0} \cdot dNE_{qt}}{EC_{it_0}} \tag{D.10}$$

$$ss_i = \frac{\sum_{q \in setP} \cdot cf_{q,t_0} \cdot dNE_{qt}}{EC_{it_0}} \tag{D.11}$$

In these equations, numerators are the total cost of the corresponding inputs while total energy cost takes place in the denominators.

Estimation of the sectoral elasticity of substitution parameters, σ_i's, is maybe the knottiest part of this study. Because, as far as we know, there is no study on estimation of these elasticities for Turkey and a wide range of values, even for the entire economy, have been used for the other countries. In ETA-Macro type models, for example, σ is generally assumed to be 0.30 or 0.35 for the overall economy. Kemfert [59] criticizes the high variety of estimates for elasticities in the literature and presents estimates by analyzing various nesting structures in the CES function. However, her results are restricted with the industry sector in Germany.

In order to resolve this conflict to some extend, it is decided to run the model for combinations of several levels of σ_i (0.25, 0.35 and 0.45). Based on all of the preliminary experiments, our observations, analogical arguments and regarding the general trend of the Turkish economy, σ_i values are assumed to be 0.40, 0.35, 0.35, 0.30 and 0.35 for *Agriculture*, *Industry: Energy-intensive*, *Industry: Other*, *Services* and *Transportation*, respectively. A higher value for *Agriculture* and a lower value for *Services* is consistent with our preliminary studies and is intuitive. Although these elasticities are high compared to the ones used in one-sector models [4], [11], [41], [44] and [45]; using higher elasticities in the the multi-sector model is justified by Kemfert [59]. That is, in a similar setting with our model (nested CES function comprising aggregate of capital-labor and energy), Kemfert comes up with higher elasticities for the sub-sectors, compared to the elasticity for the overall industry sector.

Shares of capital and labor, sk_i and sl_i pairs, are calibrated as 0.55-0.45, 0.65-0.35, 0.65-0.35, 0.65-0.35 and 0.80-0.20 for *agriculture*, *energy-intensive industry*, *other industry*, *services* and *transportation*, respectively. These values are obtained using the sectoral labor payments and operational surpluses, [60] and [72].

Note that a_i and b_i values can be converted into α_i and γ_i through the following equations.

$$\gamma_i = (a_i + b_i)^{\frac{1}{\rho_i}} \tag{D.12}$$

$$\alpha_i = \frac{a_i}{(a_i + b_i)} \tag{D.13}$$

Recall that the objective of our model is:

$$\max \sum_{t=t_0}^{T} \Delta_t \left[\sum_{i=1}^{n} \theta_i log((C_{it}^F)^{sc_i^f} (C_{it}^D)^{sc_i^d}) \right] + \frac{\Delta_{(T+1)}(1+g)}{1 - \frac{(1+g)}{(1+\delta)}} \sum_{i=1}^{n} \theta_i log((C_{iT}^F)^{sc_i^f} (C_{iT}^D)^{sc_i^d})$$

The share parameter for sector i, θ_i, is determined as follows:

$$\theta_i = \frac{C_{it_0}}{\sum_{j=1}^{n} C_{jt_0}} \tag{D.14}$$

Domestic and foreign shares of the consumption goods, sc_i^d and sc_i^f, are calibrated through the following equations:

Table D.1: Parameters: Gross Output Function.

	Agriculture	Industry: Energy Intensive	Industry: Other	Services	Transportation
sk	0.55	0.65	0.65	0.65	0.80
sl	0.45	0.35	0.35	0.35	0.20
se	0.343	0.495	0.524	0.675	0.028
sp	0.657	0.290	0.227	0.089	0.972
sng	0	0.069	0.105	0.097	0
ss	0	0.146	0.144	0.139	0
sc^d	0.989	0.724	0.929	0.993	0.997
sc^f	0.011	0.276	0.071	0.007	0.003
σ	0.40	0.35	0.35	0.30	0.35
λ^K	0.960	0.960	0.960	0.965	0.960
λ	0.970	0.970	0.970	0.970	0.970
θ	0.079	0.024	0.251	0.547	0.099
α	0.282	0.074	0.277	0.853	0.799
γ	124.170	16.651	26.107	47.313	3.818

$$sc^d = \frac{C^D_{it_0}}{C_{it_0}}, \quad sc^f = \frac{C^F_{it_0}}{C_{it_0}} \tag{D.15}$$

Finally, all parameters related to gross output functions and objective function are summarized in Table D.1. Note that we employ the same annual survival factor for all inputs except for the capital stock which are estimated based on [71]. The growth rate for the total factor productivity is set to 2% at the base year for industry with a decreasing trend, to 1.0% for services with an increasing trend and to 0.50% for agriculture. That is, γ_i values presented in Table D.1 denote the base year values which are increased by aforementioned coefficients throughout the planning horizon. g, the post-horizon growth rate, is assumed to be 0.03 and δ is set to 10%.

D.2 PARAMETERS: INTER-SECTORAL FLOWS

Calibration of some of the parameters related to inter-sectoral flows of intermediate and investment goods has already been explained in Section 4.1. Recall that ${st^d}_{ji}$ and ${st^f}_{ji}$ are calculated through the following equations.

$$st^{d}{}_{ji} = \frac{Inter^{D}{}_{jit_0}}{Y_{it_0}} \qquad \forall i, j$$

$$st^{f}{}_{ji} = \frac{Inter^{F}{}_{jit_0}}{Y_{it_0}} \qquad \forall i, j$$

$\overline{Int_t}$ and $\underline{Int_t}$, which are employed to allow marginal substitution possibilities for the flows of intermediate goods, are set to 1.025 with an increasing trend up to 1.100 and to 0.975 with a decreasing trend down to 0.900 by the end of the planning horizon, respectively.

Table D.2: Parameters: st^{d}_{ji} and st^{f}_{ji}.

	Agriculture	Industry: Energy-intensive	Industry: Other	Services	Transportation
st^{d}_{ji}					
Agriculture	0.143	0.006	0.107	0.009	0.000
Industry: Energy-intensive	0.027	0.188	0.067	0.037	0.006
Industry: Other	0.048	0.105	0.251	0.071	0.045
Services	0.070	0.132	0.129	0.200	0.223
Transportation	0.016	0.046	0.041	0.029	0.080
st^{f}_{ji}					
Agriculture	0.004	0.003	0.009	0.000	0.000
Industry: Energy-intensive	0.009	0.128	0.057	0.011	0.000
Industry: Other	0.005	0.022	0.067	0.015	0.016
Services	0.002	0.003	0.002	0.004	0.003
Transportation	0.000	0.001	0.001	0.006	0.017

Similarly, as explained in Section 4.1, sv^{d}_{ji} and sv^{f}_{ji} are computed from the base year data as follows:

$$sinv^{d}{}_{ij} = \frac{Invest^{D}_{ijt_0}}{\sum_{i'j'} Invest_{i'j't_0}} \qquad \forall i, j$$

$$sinv^{f}{}_{ij} = \frac{Invest^{F}_{ijt_0}}{\sum_{i'j'} Invest_{i'j't_0}} \qquad \forall i, j$$

$\overline{Inv_t}$ and $\underline{Inv_t}$ have the same roles with $\overline{Int_t}$ and $\underline{Int_t}$ but for the flows of investments. $\overline{Inv_t}$ and $\underline{Inv_t}$ are set at 0.50 and 1.50, respectively.

Table D.3: Parameters: $sinv^d_{ji}$ and $sinv^f_{ji}$.

	Agriculture	Industry: Energy-intensive	Industry: Other	Services	Transportation
$sinv^d_{ji}$					
Agriculture	0.000	0.000	0.000	0.000	0.000
Industry: Energy-intensive	0.000	0.000	0.000	0.000	0.000
Industry: Other	0.009	0.007	0.030	0.099	0.040
Services	0.026	0.022	0.091	0.297	0.119
Transportation	0.001	0.001	0.005	0.015	0.006
$sinv^f_{ji}$					
Agriculture	0.000	0.000	0.000	0.000	0.000
Industry: Energy-intensive	0.000	0.000	0.000	0.000	0.000
Industry: Other	0.011	0.009	0.038	0.123	0.049
Services	0.000	0.000	0.000	0.000	0.000
Transportation	0.000	0.000	0.000	0.000	0.000

D.3 PARAMETERS: FOREIGN TRADE

$\overline{F}_t$, $\overline{M_i}$ and $\underline{X_i}$ were defined in Section 4.1 to be employed in the following equations.

$$F_t \leq \overline{F}_t \cdot GDP_t \qquad \forall t$$

$$X_{it} \geq \underline{X_i} \cdot VA_{it} \qquad \forall i, t$$

$$M_{it} \leq \overline{M_i} \cdot VA_{it} \qquad \forall i, t$$

where $\overline{M_i} = 1.05 \frac{M_{it_0}}{VA_{it_0}}$ and $\overline{X_i} = 0.95 \frac{X_{it_0}}{VA_{it_0}}$ for all i. Table D.4 lists the values of $\overline{M_i}$ and $\underline{X_i}$ for each sector.

Table D.4: Parameters: Foreign Trade.

	Agriculture	Industry: Energy-intensive	Industry: Other	Services	Transportation
$\overline{M_i}$	0.072	1.659	0.885	0.017	0.094
$\underline{X_i}$	0.057	0.483	0.681	0.064	0.170

F_t, on the other hand, is calibrated as 4% for 2004, 3.4% for 2005 and assumed to be 6% for the rest of the planning horizon referring to [73].

D.4 PARAMETERS: CAPITAL ACCUMULATION

As noted in Section 4.1, different from the one-sector model where new capital is determined simply by adding the certain proportions of the current and previous years' investments, capital formation is represented by a Cobb-Douglas function of sectoral investments in the multi-sector model. Share parameters, sv^d_{ji} and sv^f_{ji}, are determined by the following equations and resulting values are tabulated in Table D.5. Note that values in the same row are equal since total investment demand for the goods of a sector is distributed among the sectors based on sectoral capital stocks, as explained in Section C.2.

$$sv^d_{ji} = \frac{Invest^D_{jit_0}}{\sum_{j'} Invest_{j'it_0}} \qquad \forall i, j$$

$$sv^f_{ji} = \frac{Invest^F_{jit_0}}{\sum_{j'} Invest_{j'it_0}} \qquad \forall i, j$$

Table D.5: Parameters: sv^d_{ji} and sv^f_{ji}.

	Agriculture	Industry: Energy-intensive	Industry: Other	Services	Transportation
sv^d_{ji}					
Agriculture	0.000	0.000	0.000	0.000	0.000
Industry: Energy-intensive	0.000	0.000	0.000	0.000	0.000
Industry: Other	0.185	0.185	0.185	0.185	0.185
Services	0.556	0.556	0.556	0.556	0.556
Transportation	0.028	0.028	0.028	0.028	0.028
sv^f_{ji}					
Agriculture	0.000	0.000	0.000	0.000	0.000
Industry: Energy-intensive	0.000	0.000	0.000	0.000	0.000
Industry: Other	0.230	0.230	0.230	0.230	0.230
Services	0.000	0.000	0.000	0.000	0.000
Transportation	0.000	0.000	0.000	0.000	0.000

Scale parameter for capital accumulation, μ_i, is calibrated using the base year investment amounts as follows.

$$\mu_i = \frac{\sum_{j=1}^{n} Invest_{jit_0}}{\prod_j (Invest^D)^{sv^d_{ji}}_{j,i,t_0} \cdot (Invest^F)^{sv^f_{ji}}_{j,i,t_0}}$$

where μ_i values are all equal to 2.953.

D.5 PARAMETERS: CHANGES IN ANNUAL ENERGY CONSUMPTIONS

Sudden and sharp increases in domestic energy production as well as total energy supply are unusual to be observed since it is a matter of finance and time for large capacities to be made happen in a short time. The term capacity here does not only refer to the production capacities but also the capacity for transporting and importing energy resources (capacity of ports and pipelines). Sudden declines, on the other hand, would not be possible due to the cost of unused factors of production and the long-term supply contracts (for example the contracts presented in Table 3.6). Then, we have defined several sets of lower and upper bounds in order to avoid high fluctuations in energy demand and supply. These bounding parameters are grouped based on the variables which they restrict:

- Annual changes in total supply of energy resources
- Annual changes in sectoral consumptions of energy resources
- Newly added incremental capacity of the electricity generating units

Determining the levels of bounding parameters is a critical issue since these parameters should give enough room for the model to represent substitution possibilities while regarding the short and medium-term plans for which significant actions have already been taken in the economy. For example, we cannot avoid setting positive lower bounds for incremental capacities of natural gas plants knowing that there are short and medium-term gas contracts and significant investments which have not yet been finalized.

Following inequalities were defined Section 4.2 to restrict annual increments of primary energy supplies.

$$totP_{qt} \leq totUP_{qt} \cdot totP_{q,(t-1)} \qquad \forall t > t_0, q \in setFF$$

$$totP_{qt} \geq totLOW_{qt} \cdot totP_{q,(t-1)} \qquad \forall t > t_0, q \in setFF$$

where $totUP_{qt}$ and $totLOW_{qt}$ are the coefficients to set upper and lower bounds on the annual changes. Table D.6 lists the $totUP_{qt}$ and $totLOW_{qt}$ values for each q and t. Note that tighter intervals are given for domestic resources compared to those employed for imported fuels since increase in domestic production also requires expansion of the production units. Besides this, wood and domestic oil production are restricted by the current levels of production based on the historical data and government projections. Finally, short and medium term gas contracts cause higher lower bounds for natural gas than those set for the rest of the fuels.

Table D.6: Parameters: $totUP_{qt}$ and $totLOW_{qt}$.

	$totUP_{qt}$	$totLOW_{qt}$
Domestic Coal	1.10 from 2005 to 2030	0.90 from 2005 to 2030
Domestic Petroleum Products	1.00 from 2005 to 2030	
Lignite$_1$	1.10 from 2005 to 2030	
Lignite$_2$	1.10 from 2005 to 2030	
Lignite$_3$	1.10 from 2005 to 2030	
Wood	1.00 from 2005 to 2030	
Imported Coal	1.15 from 2005 to 2030	0.85 from 2005 to 2030
Imported Petroleum Products		0.85 from 2005 to 2030
Natural Gas		1.00 from 2005 to 2020
		0.95 from 2021 to 2030

In addition to the limiting constraints presented above, we also set bounds on sectoral consumption of solid fuels and petroleum products. As seen in Table D.7, we have assumed an equal and high level of substitution opportunity among energy inputs in each sector.

$$dNE_{iqt} \leq secUP_{qt} \cdot dNE_{iq,t-1} \qquad t \geq t+1, q \in (setS \cup setP)$$

$$dNE_{iqt} \geq secLOW_{qt} \cdot dNE_{iq,t-1} \qquad t \geq t+1, q \in (setS \cup setP)$$

As noted in Section 4.2, above constraints are written only for solid fuels and petroleum products but not for the natural gas and electricity, since Equation 4.17 is sufficient to control annual flows of sectoral natural gas and electricity demands.

Table D.7: Parameters: $secUP_{qt}$ and $secLOW_{qt}$.

	$secUP_{qt}$	$secLOW_{qt}$
Domestic Coal	1.20 from 2005 to 2030	0.80 from 2005 to 2030
Domestic Petroleum Products		
Lignite		
Wood		
Imported Coal		
Imported Petroleum Products		

For electricity, additional bounds exist on incremental capacities (flows) of electricity generation units as follows.

$$newE_{qt} \leq IncUP_{qt} \cdot dE_{q,t-1} \qquad \forall t > t_0, q \in setE \qquad \text{(D.16)}$$

$$newE_{qt} \geq IncLOW_{qt} \cdot dE_{q,t-1} \qquad \forall t > t_0, q \in setE \qquad \text{(D.17)}$$

As seen from Table D.8, $incLOW_{qt}$ values are all set to 0 except *Natural Gas*, therefore declines for a specific technology are provided by retirement of those plants once they complete their economic lifetimes. For *Natural Gas* power plants, on the other hand, positive lower bounds are assumed due to the gas contracts presented in Table 3.6 and short-term plans in the power sector.

When setting $incUP_{qt}$ values, actual data up to 2010 and applications waiting in the pipeline are taken into account, for example, licence applications for wind turbines have already exceeded the national potential.

Finally, instead of setting upper and lower bounds for incremental capacities of nuclear power plants and solar electricity, we have set upper bounds on possible capacities of these resources. That is, we have fixed electricity generated by the nuclear power plants to 0 until 2020 and set stepwise upper bounds which increase by the years 2020, 2022 and 2025. Similarly, solar electricity is fixed to 0 until 2013 and allowed to increase by 1 GW in each year afterwards.

Table D.8: Parameters: $incUP_{qt}$ and $incLOW_{qt}$.

	$incUP_{qt}$	$incLOW_{qt}$
Hydro Dam	0.05 from 2005 to 2010 0.10 from 2010 to 2030	0 from 2005 to 2030
Hydro River	0.05 from 2005 to 2010 0.10 from 2010 to 2030	0 from 2005 to 2030
$Lignite_1$	0.10 from 2005 to 2010 0.20 from 2011 to 2030	0 from 2005 to 2030
$Lignite_2$	0.10 from 2005 to 2010 0.20 from 2011 to 2030	0 from 2005 to 2030
$Lignite_3$	0.10 from 2005 to 2010 0.20 from 2011 to 2030	0 from 2005 to 2030
Imported Coal 0.20 from 2011 to 2030	0.10 from 2005 to 2010	0 from 2005 to 2030
Imported Petroleum Products	0.20 from 2005 to 2030	0 from 2005 to 2030
Natural Gas	0.20 from 2005 to 2030	0.075 from 2005 to 2010 0.040 from 2011 to 2020 0 from 2021 to 2030
Wind	1 from 2005 to 2010 0.25 from 2011 to 2015 0.20 from 2005 to 2030	0 from 2005 to 2030
Geothermal	0.20 from 2005 to 2030	0 from 2005 to 2030
Solar *Nuclear*	NA NA	NA NA

APPENDIX E

ONE-SECTOR MODEL

E.1 SETS

$setE$	Set of electricity generating technologies.
$setS$	Set of solid fuel types used for non-electric energy.
$setP$	Set of petroleum products used for non-electric energy.
$setN$	Set of gas resources used for non-electric energy.
$setNE$	Set of all energy resources used for non-electric energy.
$setBOTH$	Set of fuels used for both generating electricity and non-electric energy.
$setL$	Set of lignite types.
$setFF$	Set of fossil fuels including $Wood$.

$setE$ = $\{HydroDam, HydroRiver, Imported\ Coal, Imported\ Petroleum\ Products, Lignite_1, Lignite_2, Lignite_3, Natural\ Gas, Nuclear, Wind, Solar, Geothermal\}$.

$setS$ = $\{Domestic\ Coal, Imported\ Coal, Lignite, Wood\}$.

$setP$ = $\{Domestic\ Petroleum\ Products, Imported\ Petroleum\ Products\}$.

$setN$ = $\{Natural\ Gas\}$.

$setNE$ = $setS \cup setP \cup setN$.

$setBOTH$ = $\{Imported\ Coal, Imported\ Petroleum\ Products, Lignite_1, Lignite_2, Lignite_3, Natural\ Gas\}$.

$setL$ = $\{Lignite_1, Lignite_2, Lignite_3\}$.

$setFF$ = $\{Imported\ Coal, Imported\ Petroleum\ Products, Lignite_1, Lignite_2, Lignite_3, Natural\ Gas, Domestic\ Coal, Domestic\ Petroleum\ Products, Wood\}$.

E.2 VARIABLES

C_t	Consumption in year t.
C_t^F	Consumption in year t-foreign.
C_t^D	Consumption in year t-domestic.
E_t	Electricity consumption in year t.
EN_t	Newly added incremental electricity supply in year t.
EC_t	Energy Cost in year t.
EC_t^F	Energy Cost in year t-foreign.
EC_t^D	Energy Cost in year t-domestic.
F_t	Foreign capital inflows including workers' remittances in year t.
GDP_t	Gross Domestic Product in year t.
INT_t	Intermediate goods demand in year t-foreign.
$INTN_t$	Increment of intermediate goods demand in year t-foreign.
INV_t	Investment in year t.
INV_t^F	Investment in year t-foreign.
INV_t^D	Investment in year t-domestic.
K_t	Total capital stock in year t.
KN_t	Newly added incremental capital stock in year t.
L_t	Labor in year t.
LN_t	Increment of labor in year t.
M_t	Imports in year t.
N_t	Natural gas consumption for non-electric use in year t.
NN_t	Increment of natural gas consumption for non-electric use in year t.
P_t	Petroleum products consumption for non-electric use in year t.
PN_t	Increment of petroleum products consumption for non-electric use in year t.
S_t	Solid fuels consumption for non-electric use in year t.
SN_t	Increment of solid fuels consumption for non-electric use in year t.
X_t	Exports in year t.
Y_t	Gross Output in year t.
YN_t	Increment of Gross Output in year t.

dE_{qt}	Electricity generation from resource $q \in setE$ in year t.
dNE_{qt}	Energy supplied in year t for non-electric use where $q \in setNE$.
$newE_{qt}$	Incremental (flow) electricity coming on line from resource $q \in setE$ in year t
$totP_{qt}$	Total supply of primary fossil fuel $q \in setFF$ in year t.
$Emission_{gg,t}$	Emission of GHG gg in year t.
$totEmission_t$	Total GHG emissions in year t.

E.3 PARAMETERS

λ^{INPUT}	Survival factor (1-stock depreciation) for the inputs $\{K, L, E, P, N, S, INT\}$.
λ^{Y}	Survival factor (1-stock depreciation) for gross output.
a_1	Coefficient of the capital-labor aggregate in the production function.
a_2	Coefficient of the imported intermediates in the production function.
a_3	Coefficient of the energy aggregate in the production function.
sk	Value share of capital.
sl	Value share of labor.
se	Value share of electricity.
sp	Value share of petroleum products.
sng	Value share of natural gas.
ss	Value share of solid fuels.
ρ	$\frac{\sigma-1}{\sigma}$
σ	Elasticity of substitution among aggregates in the production function.
α, β	Scale parameters.
γ_t	Technological progress (shift) parameter in year t.
er_t	Exchange rate in year t.
$\overline{F_t}$	Upper bound parameter for F_t
$\underline{X}$	Lower bound parameter for X_t
$\overline{M}$	Upper bound parameter for M_t
sc^d, sc^f	Value share of domestic/foreign consumption goods.

g	Post-horizon growth rate.
t	Year.
t_0	Base year.
T	Terminating year.
Δ_t	Compounded cost/utility discount rate.
δ	Annual cost/utility discount rate.
$Reserve_q$	Reserve of resource $q \in (setL \cup \{Domestic\ Coal, Domestic\ Petroleum\ Products\})$.
$Potential_q$	Potential of resource $q \in \{HydroDam, HydroRiver, Wind, Solar, Geothermal\}$ in year t.
$conv_q$	Amount of $q \in setBOTH$ required to generate one unit of electricity..
$totUP_{qt}$	Upper bound parameter for annual change in total supply of $q \in (setBOTH \cup \{Domestic\ Coal, Domestic\ Petroleum\ Products\})$ in year t.
$totLOW_{qt}$	Lower bound parameter for annual change in total supply of $q \in (setBOTH \cup \{Domestic\ Coal, Domestic\ Petroleum\ Products\})$ in year t.
$incUP_{qt}$	Upper bound parameter for newly installed power plants of type $q \in setE$ in year t.
$incLOW_{qt}$	Lower bound parameter for newly installed power plants of type $q \in setE$ in year t.
cf_{qt}	Unit cost of fuel $q \in (setFF \cup \{Nuclear\})$ in year t.
co_{qt}	Unit cost of operation & maintenance in plant $q \in setE$ in year t.
ci_{qt}	Unit investment cost of plant $q \in setE$ in year t.
$coef_{T\&D}$	Coefficient to incorporate transmission and distribution costs.
$\tau_{qt}^{fuel}, \tau_{qt}^{inv}$	Shares of foreign components in fuel and investment costs.
$ef_{q,gg}$	Emission factor- GHG gg due to resource $q \in \{Coal, Natural\ Gas, Lignite, Petroleum\ Products, Wood\}$.

E.4 MACROECONOMIC MODULE

$$YN_t = \gamma_t[\alpha(KN_t^{sk}LN_t^{sl})^\rho + \beta INTN_t^\rho + (1-\alpha-\beta)(EN_t^{se}PN_t^{sp}NN_t^{sng}SN_t^{ss})^\rho]^{(\frac{1}{\rho})} \quad \forall t > t_0 \quad \text{(E.1)}$$

$$Y_t = YN_t + \lambda^Y \cdot Y_{t-1} \quad \forall t > t_0 \quad \text{(E.2)}$$

$$INPUT_t = INPUTN_t + \lambda^{INPUT} \cdot INPUT_{t-1} \quad \forall t > t_0 \quad \text{(E.3)}$$

$$INPUT \in \{K,\ L,\ E,\ P,\ N,\ S,\ INT\}$$

$$KN_t = \frac{1}{2} \cdot INV_{t-1} + \frac{1}{2} INV_t \quad \forall t > t_0 \quad \text{(E.4)}$$

$$INV_t = INV_t^D + er_t \cdot INV_t^F \quad \forall t \quad \text{(E.5)}$$

$$C_t = C_t^D + er_t \cdot C_t^F \quad \forall t \quad \text{(E.6)}$$

$$EC_t = EC_t^D + er_t \cdot EC_t^F \quad \forall t \quad \text{(E.7)}$$

$$M_t = INV_t^F + EC_t^F + INT_t + C_t^F \quad \forall t \quad \text{(E.8)}$$

$$M_t \leq X_t + F_t \quad \forall t \quad \text{(E.9)}$$

$$GDP_t = C_t + INV_t + er \cdot (X_t - M_t) \quad \forall t \quad \text{(E.10)}$$

$$Y_t = GDP_t + er \cdot INT_t + EC_t \quad \forall t \quad \text{(E.11)}$$

$$C_t = Y_t - INV_t^D - er_t \cdot X_t - EC_t^D + er_t \cdot C_t^F \quad \forall t \quad \text{(E.12)}$$

$$F_t \leq \overline{F}_t \cdot GDP_t \quad \forall t \quad \text{(E.13)}$$

$$X_t \geq \underline{X} \cdot GDP_t \quad \forall t \quad \text{(E.14)}$$

$$M_t \leq \overline{M} \cdot GDP_t \quad \forall t \quad \text{(E.15)}$$

Objective Function:

$$\max \sum_{t=t_0}^{T} \Delta_t \left[log((C_t^F)^{sc^f} (C_t^D)^{sc^d}) \right] + \frac{\Delta_{(T+1)}(1+g)}{1 - \frac{(1+g)}{(1+\delta)}} log((C_T^F)^{sc^f} (C_T^D)^{sc^d}) \quad \text{(E.16)}$$

E.5 ENERGY MODULE

$$S_t = \sum_{q \in setS} dNE_{qt} \qquad \forall t \qquad (E.17)$$

$$P_t = \sum_{q \in setP} dNE_{qt} \qquad \forall t \qquad (E.18)$$

$$N_t = \sum_{q \in setN} dNE_{qt} \qquad \forall t \qquad (E.19)$$

$$E_t = \sum_{q \in setE} dE_{qt} \qquad \forall t \qquad (E.20)$$

$$totP_{qt} = conv_q \cdot dE_{qt} + dNE_{qt} \qquad \forall t, q \in setBOTH \qquad (E.21)$$

$$totP_{qt} = dNE_{qt} \qquad \forall t, q \in (setFF \backslash setBOTH) \qquad (E.22)$$

$$\sum_{t=t_0}^{t=T} totP_{qt} \leq Reserve_q \qquad q \in (setL \cup \{Dom.\ Coal,\ Dom.\ Pet.\ Products\}) \qquad (E.23)$$

$$dE_{qt} \leq Potential_q \quad q \in \{HydroDam,\ HydroRiver,\ Wind,\ Solar,\ Geothermal\},\ \forall t \qquad (E.24)$$

$$totP_{qt} \leq totUP_{qt} \cdot totP_{q,(t-1)} \qquad \forall t > t_0, q \in setFF \qquad (E.25)$$

$$totP_{qt} \geq totLOW_{qt} \cdot totP_{q,(t-1)} \qquad \forall t > t_0, q \in setFF \qquad (E.26)$$

$$dE_{qt} = dE_{q,(t-1)} + newE_{qt} - dE_{q,(t-t_q)} \qquad q \in setE, \forall t > t_0 \qquad (E.27)$$

$$newE_{qt} \leq IncLOW_{qt} \cdot dE_{q,t-1} \qquad q \in setE, \forall t > t_0 \qquad (E.28)$$

$$newE_{qt} \geq IncUP_{qt} \cdot dE_{q,t-1} \qquad q \in setE, \forall t > t_0 \qquad (E.29)$$

$$EC_t^D = \sum_{q \in setNE} (1 - \tau_{qt}^{fuel}) \cdot cf_{q,t} \cdot dNE_{qt} + coef_{T\&D} \cdot (\sum_{q \in setBOTH} (1 - \tau_{qt}^{fuel}) \cdot cf_{q,t} \cdot conv_q \cdot dE_{qt} + \sum_{q \in setE} (co_{q,t} + (1 - \tau_{qt}^{inv}) \cdot ci_{q,t}) \cdot dE_{qt}) \qquad \forall t \qquad (E.30)$$

$$EC_t^F = \sum_{q \in setNE} \tau_{qt}^{fuel} \cdot cf_{q,t} \cdot dNE_{qt} + coef_{T\&D} \cdot (\sum_{q \in setBOTH} \tau_{qt}^{fuel} \cdot cf_{q,t} \cdot conv_q \cdot dE_{qt} + \sum_{q \in setE} \tau_{qt}^{inv} \cdot ci_{q,t} \cdot dE_{qt}) \qquad \forall t \qquad (E.31)$$

E.6 ENVIRONMENT MODULE

$$
\begin{aligned}
Emission_{CO_2,t} = {} & ef_{Coal,CO_2} \cdot (totP_{Dom.Coal,t} + totP_{Imp.Coal,t}) + \\
& ef_{Lignite,CO_2} \cdot \sum_{q \in setL} totP_{q,t} + \\
& ef_{Pet.Prod.,CO_2} \cdot (totP_{Dom.Pet.Prod.,t} + totP_{Dom.Pet.Prod.,t}) + \\
& ef_{NaturalGas,CO_2} \cdot totP_{NaturalGas,t} \qquad \forall t
\end{aligned}
\tag{E.32}
$$

$$
\begin{aligned}
Emission_{CH_4,t} = {} & ef_{Coal,CH_4} \cdot totP_{DomesticCoal,t} + ef_{Lignite,CH_4} \cdot \sum_{q \in setL} totP_{q,t} + \\
& ef_{Wood,CH_4} \cdot totP_{Wood,t} \qquad \forall t
\end{aligned}
\tag{E.33}
$$

$$
\begin{aligned}
Emission_{N_2O,t} = {} & ef_{Coal,N_2O} \cdot (totP_{Dom.Coal,t} + totP_{Imp.Coal,t}) + \\
& ef_{Lignite,N_2O} \cdot \sum_{q \in setL} totP_{q,t} + \\
& ef_{Pet.Prod.,N_2O} \cdot (totP_{Dom.Pet.Prod.,t} + totP_{Imp.Pet.Prod.,t}) + \\
& ef_{Wood,N_2O} \cdot totP_{Wood,t} + ef_{Nat.Gas,N_2O} \cdot totP_{Nat.Gas,t} \qquad \forall t
\end{aligned}
\tag{E.34}
$$

$$
totEmission_t = Emission_{CO_2,t} + Emission_{CH_4,t} + Emission_{N_2O,t} \qquad \forall t \tag{E.35}
$$

APPENDIX F

MULTI-SECTOR MODEL

F.1 VARIABLES

C_{it}	Consumption of good i in year t.
C_{it}^F	Consumption of foreign good i in year t.
C_{it}^D	Consumption of domestic good i in year t.
E_{it}	Electricity demand in sector i and year t.
EC_{it}	Energy cost in sector i and year t.
EC_{it}^F	Foreign component of energy cost in sector i and year t.
EC_{it}^D	Domestic component of energy cost in sector i and year t.
EN_{it}	Increment of electricity demand in sector i and year t.
F_t	Foreign capital inflows including workers' remittances in year t.
GDP_t	Gross Domestic Product in year t.
$Inter_{ijt}$	Demand for intermediate good i in sector j and year t.
$Inter_{ijt}^F$	Demand for foreign intermediate good i in sector j and year t.
$Inter_{ijt}^D$	Demand for domestic intermediate good i in sector j and year t.
$Invest_{ijt}$	Demand for investment good i in sector j and year t.
$Invest_{ijt}^F$	Demand for foreign investment good i in sector j and year t.
$Invest_{ijt}^D$	Demand for domestic investment good i in sector j and year t.
$IntToY_{it}$	Intermediate goods to gross output ratio in sector i and year t.
K_{it}	Total capital stock in sector i and year t.
KN_{it}	Newly added incremental capital stock in sector i and year t.

L_{it}	Labor in sector i and year t.
LN_{it}	Increment of labor in sector i and year t.
M_{it}	Imports of good i in year t.
N_{it}	Natural gas consumption for non-electric use in sector i and year t.
NN_{it}	Increment of natural gas consumption for non-electric use in sector i and year t.
NRH_t	"Final consumption expenditure of non-resident households on the economic territory in year t."
P_{it}	Petroleum products consumption for non-electric use in sector i and year t.
PN_{it}	Increment of petroleum products consumption for non-electric use in sector i and year t.
S_{it}	Solid fuels consumption for non-electric use in sector i and year t.
SN_{it}	Increment of solid fuels consumption for non-electric use in sector i and year t.
$TotL_t$	Total labor force in year t.
$TotM_t$	Total imports in year t.
$TotX_t$	Total exports in year t.
VA_{it}	Value-added in sector i and year t.
X_{it}	Exports of good i in year t.
Y_{it}	Gross Output in sector i and year t.
YN_{it}	Increment of Gross Output in sector i and year t.
dE_{qt}	Electricity generation from resource $q \in setE$ in year t.
dL_{qt}	Lignite of type $q \in setL$ supplied for non-electric use in year t.
dNE_{iqt}	Energy demand in sector i and year t for non-electric use where $q \in setNE$.
$newE_{qt}$	Incremental (flow) electricity coming on line from resource $q \in setE$ in year t
$p_{Elec,t}$	Average cost of electricity in year t.
$p_{Lignite,t}$	Average cost of lignite in year t.
$totP_{qt}$	Total supply of primary fossil fuel $q \in setFF$ in year t.
$EmissionNE_{i,gg,t}$	Emission of GHG gg in sector i and year t.
$EmissionElec_t$	GHG emission due to electricity generation in year t.
$totEmission_t$	Total GHG emissions in year t.

F.2 PARAMETERS

λ_i^{INPUT}	Survival factor (1-stock depreciation) for the inputs $\{K, L, E, P, N, S, INT\}$ in sector *i*.
λ_i^{Y}	Survival factor (1-stock depreciation) for gross output in sector *i*.
a_{1i}	Coefficient of the capital-labor aggregate in the production function of sector *i*.
a_{2i}	Coefficient of the energy aggregate in the production function of sector *i*.
sk_i	Value share of capital in sector *i*.
sl_i	Value share of labor in sector *i*.
se_i	Value share of electricity in sector *i*.
sp_i	Value share of petroleum products in sector *i*.
sng_i	Value share of natural gas in sector *i*.
ss_i	Value share of solid fuels in sector *i*.
ρ_i	$\frac{\sigma_i - 1}{\sigma_i}$
σ_i	Elasticity of substitution among aggregates in the production function of sector *i*.
α_i, μ_i	Scale parameters in sector *i*.
γ_{it}	Technological progress (shift) parameter in sector *i*.
er_t	Exchange rate in year *t*.
$\overline{F_t}$	Upper bound parameter for F_t
$\underline{X_i}$	Lower bound parameter for X_{it}
$\overline{M_i}$	Upper bound parameter for M_{it}
$\underline{Inv_t}, \overline{Inv_t}$	Lower/upper bound parameters which define an interval that allows substitution of investment goods among sectors.
$\underline{Int_t}, \overline{Int_t}$	Lower/upper bound parameters which define an interval that allows substitution of intermediate goods among sectors.
$sinv_{ij}^d, sinv_{ij}^f$	Share value of domestic/foreign investment goods i demanded in sector j-within all investments.
st_{ij}^d, st_{ij}^f	Share value of domestic/foreign intermediate goods i demanded in sector j-within all intermediates in sector *j*.
sv_{ij}^d, sv_{ij}^f	Share value of domestic/foreign investment goods i demanded in sector j-within all investments in sector j.
sc_i^d, sc_i^f	Value share of domestic/imported consumption goods in sector *i*.

θ_i	Value share of consumption good i-within total consumption.
g	Post-horizon growth rate.
t	Year.
t_0	Base year.
T	Terminating year.
Δ	Compounded cost/utility discount rate.
δ	Annual cost/utility discount rate.
$Reserve_q$	Reserve of resource $q \in (setL \cup \{Domestic\ Coal, Domestic\ Petroleum\ Products\})$.
$Potential_q$	Potential of resource $q \in \{HydroDam, HydroRiver, Wind, Solar, Geothermal\}$ in year t.
$conv_q$	Amount of $q \in setBOTH$ required to generate one unit of electricity.
$totLOW_{qt}$	Lower bound parameter for annual change in total supply of $q \in (setBOTH \cup \{Domestic\ Coal, Domestic\ Petroleum\ Products\})$ in year t.
$totUP_{qt}$	Upper bound parameter for annual change in total supply of $q \in (setBOTH \cup \{Domestic\ Coal, Domestic\ Petroleum\ Products\})$ in year t.
$secLOW_{qt}$	Lower bound parameter for annual change in sectoral demand of $q \in (setS \cup setP)$ in year t.
$secUP_{qt}$	Upper bound parameter for annual change in sectoral demand of $q \in (setS \cup setP)$ in year t.
$incLOW_{qt}$	Lower bound parameter for newly installed power plants of type $q \in setE$ in year t.
$incUP_{qt}$	Upper bound parameter for newly installed power plants of type $q \in setE$ in year t.
cf_{qt}	Unit cost of fuel $q \in (setFF \cup \{Nuclear\})$ in year t.
co_{qt}	Unit cost of operation & maintenance in plant $q \in setE$ in year t.
ci_{qt}	Unit investment cost of plant $q \in setE$ in year t.
$coef_{T\&D}$	Coefficient to incorporate transmission and distribution costs.
$\tau_{qt}^{fuel}, \tau_{qt}^{inv}$	Shares of foreign components in fuel and investment costs.
$ef_{q,gg}$	Emission factor- GHG gg due to resource $q \in \{Coal, Natural\ Gas, Lignite, Petroleum\ Products, Wood\}$.

F.3 MACROECONOMIC MODULE

$$YN_{it} = \frac{\gamma_{it}[\alpha_i(KN_{it}^{sk_i}LN_{it}^{sl_i})^{\rho_i} + (1-\alpha_i)(EN_{it}^{se_i}PN_{it}^{sp_i}NN_{it}^{sng_i}SN_{it}^{ss_i})^{\rho_i}]^{(\frac{1}{\rho_i})}}{(1-IntToY_{it})} \quad \forall i, t > t_0 \tag{F.1}$$

$$IntToY_{it} = \frac{\sum_j Inter_{jit}}{Y_{it}} \quad \forall i, t \tag{F.2}$$

$$Y_{it} = YN_{it} + \lambda_i^Y \cdot Y_{i,t-1} \quad \forall i, t > t_0 \tag{F.3}$$

$$INPUT_{it} = INPUTN_{it} + \lambda_i^{INPUT} \cdot INPUT_{i,t-1} \quad \forall i, t > t_0 \tag{F.4}$$

$$INPUT \in \{K,\ L,\ E,\ P,\ N,\ S,\ INT\}$$

$$KN_{it} = \mu_i \prod_j (\sum_{t-1 \le t' \le t} \frac{1}{2} Invest^D{}_{j,i,t'})^{sv_{ji}^d} \cdot (\sum_{t-1 \le t' \le t} \frac{1}{2} Invest^F{}_{j,i,t'})^{sv_{ji}^f} \quad \forall i, t > t_0. \tag{F.5}$$

$$KN_{it} = \sum_{t-1 \le t' \le t} \sum_{j=1}^{n} (\frac{1}{2} Invest^D{}_{j,i,t'} + \frac{1}{2} Invest^F{}_{j,i,t'}) \quad \forall i, t > t_0. \tag{F.6}$$

$$C_{it} = C_{it}^D + er \cdot C_{it}^F \quad \forall i, t \tag{F.7}$$

$$EC_{it} = EC_{it}^D + er \cdot EC_{it}^F \quad \forall i, t \tag{F.8}$$

$$Inter_{ijt} = Inter_{ijt}^D + er \cdot Inter_{ijt}^F \quad \forall i, j, t \tag{F.9}$$

$$Invest_{ijt} = Invest_{ijt}^D + er \cdot Invest_{ijt}^F \quad \forall i, j, t \tag{F.10}$$

$$Y_{it} = \sum_{j=1}^{n} Inter_{jit} + VA_{it} + EC_{it}^D + er_t \cdot EC_{it}^F \quad \forall i, t \tag{F.11}$$

$$M_{it} = C_{it}^F + \sum_{j=1}^{n} Invest_{ijt}^F + \sum_{j=1}^{n} Inter_{ijt}^F \quad \forall i, t \tag{F.12}$$

$$TotM_t = \sum_{i=1}^{n} (M_{it} + EC_{it}^F) \quad \forall t \tag{F.13}$$

$$TotX_t = \sum_{i=1}^{n} X_{it} + NRH_t \quad \forall t \tag{F.14}$$

$$GDP_t = \sum_{i=1}^{n} VA_{it} + NRH_t \quad \forall t \tag{F.15}$$

$$TotL_t = \sum_{i=1}^{n} L_{it} \quad \forall t \tag{F.16}$$

$$TotX_t + F_t \ge TotM_t \quad \forall t \tag{F.17}$$

$$F_t \le \overline{F}_t \cdot GDP_t \quad \forall t \tag{F.18}$$

$$X_{it} \ge \underline{X_i} \cdot VA_{it} \quad \forall i, t \tag{F.19}$$

$$M_{it} \le \overline{M_i} \cdot VA_{it} \quad \forall i, t \tag{F.20}$$

$$\sum_{j=1}^{n} Inter_{jit} + VA_{it} + EC_{it}^D + er \cdot EC_{it}^F = \sum_{j=1}^{n} Inter_{ijt} + C_{it} + \sum_j Invest_{ijt} + er \cdot (X_{it} - M_{it}) \quad \forall i, t \tag{F.21}$$

$$\underline{Int_t} \cdot st^d_{ji} \cdot Y_{it} \leq Inter^D_{jit} \leq \overline{Int_t} \cdot st^d_{ji} \cdot Y_{it} \qquad \forall i, j, t \qquad (F.22)$$

$$\underline{Int_t} \cdot st^f_{ji} \cdot Y_{it} \leq Inter^F_{jit} \leq \overline{Int_t} \cdot st^f_{ji} \cdot Y_{it} \qquad \forall i, j, t \qquad (F.23)$$

$$\underline{Inv_t} \cdot sinv^d_{ij} \cdot (\sum_{i'} \sum_{j'} Invest_{i'j't}) \leq Invest^D_{ijt} \leq \overline{Inv_t} \cdot sinv^d_{ij} \cdot (\sum_{i'} \sum_{j'} Invest_{i'j't}) \qquad \forall i, j, t \qquad (F.24)$$

$$\underline{Inv_t} \cdot sinv^f_{ij} \cdot (\sum_{i'} \sum_{j'} Invest_{i'j't}) \leq Invest^F_{ijt} \leq \overline{Inv_t} \cdot sinv^f_{ij} \cdot (\sum_{i'} \sum_{j'} Invest_{i'j't}) \qquad \forall i, j, t \qquad (F.25)$$

Objective Function:

$$\max \sum_{t=t_0}^{T} \Delta_t \left[\sum_{i=1}^{n} \theta_i log((C^F_{it})^{sc^f_i} (C^D_{it})^{sc^d_i}) \right] + \frac{\Delta_{(T+1)}(1+g)}{1 - \frac{(1+g)}{(1+\delta)}} \sum_{i=1}^{n} \theta_i log((C^F_{iT})^{sc^f_i} (C^D_{iT})^{sc^d_i})$$

$$with \ \sum_{i=1}^{n} \theta_i = 1 \ \ and \ \ sc^f_i + sc^d_i = 1 \ \ for \ \ all \ \ i. \qquad (F.26)$$

F.4 ENERGY MODULE

$$S_{it} = \sum_{q \in setS} dNE_{iqt} \qquad \forall i, t \qquad (F.27)$$

$$P_{it} = \sum_{q \in setP} dNE_{iqt} \qquad \forall i, t \qquad (F.28)$$

$$N_{it} = \sum_{q \in setN} dNE_{iqt} \qquad \forall i, t \qquad (F.29)$$

$$\sum_{i=1}^{n} E_{it} = \sum_{q \in setE} dE_{qt} \qquad \forall t \qquad (F.30)$$

$$\sum_{i=1}^{n} dNE_{i,Lignite,t} = \sum_{q \in setL} dL_{qt} \qquad \forall t \qquad (F.31)$$

$$totP_{qt} = conv_q \cdot dE_{qt} + dL_{qt} \qquad \forall t, q \in setL \qquad (F.32)$$

$$totP_{qt} = conv_q \cdot dE_{qt} + \sum_{i=1}^{n} dNE_{iqt} \qquad \forall t, q \in (setBOTH \backslash setL) \qquad (F.33)$$

$$totP_{qt} = \sum_{i=1}^{n} dNE_{iqt} \qquad \forall t, q \in (setFF \backslash setBOTH) \qquad (F.34)$$

$$\sum_{t=t_0}^{t=T} totP_{qt} \leq Reserve_q \qquad q \in (setL \cup \{Domestic\ Coal,\ Domestic\ Petroleum\ Products\}) \qquad (F.35)$$

$$dE_{qt} \leq Potential_q \qquad \forall t,\ q \in \{HydroDam,\ HydroRiver,\ Wind,\ Solar,\ Geothermal\} \qquad (F.36)$$

$$dE_{qt} = dE_{q,(t-1)} + newE_{qt} - dE_{q,(t-t_q)} \qquad \forall t, q \in setE \qquad (F.37)$$

$$totP_{qt} \leq totUP_{qt} \cdot totP_{q,(t-1)} \qquad \forall t > t_0, q \in setFF \qquad (F.38)$$

$$totP_{qt} \geq totLOW_{qt} \cdot totP_{q,(t-1)} \qquad \forall t > t_0, q \in setFF \qquad (F.39)$$

$$dNE_{iqt} \leq secUP_{qt} \cdot dNE_{iq,t-1} \qquad \forall t > t_0, q \in (setS \cup setP) \qquad (F.40)$$

$$dNE_{iqt} \geq secLOW_{qt} \cdot dNE_{iq,t-1} \qquad \forall t > t_0, q \in (setS \cup setP) \qquad (F.41)$$

$$newE_{qt} \leq IncUP_{qt} \cdot dE_{q,t-1} \qquad \forall t > t_0, q \in setE \qquad (F.42)$$

$$newE_{qt} \geq IncLOW_{qt} \cdot dE_{q,t-1} \qquad \forall t > t_0, q \in setE \qquad (F.43)$$

$$p_{Lignite,t} = \frac{\sum_{q \in setL} cf_{q,t} \cdot totP_{qt}}{\sum_{q \in setL} totP_{qt}} \qquad \forall t \qquad (F.44)$$

$$p_{Elec,t} = coef_{T\&D} \cdot \frac{\sum_{q \in setBOTH} cf_{q,t} \cdot conv_q \cdot dE_{qt} + \sum_{q \in setE} (co_{q,t} + ci_{q,t}) \cdot dE_{qt}}{\sum_{q \in setE} dE_{qt}} \qquad \forall t \qquad (F.45)$$

$$\omega_t^F = coef_{T\&D} \cdot \frac{\sum_{q \in setBOTH} \tau_{qt}^{fuel} \cdot cf_{q,t} \cdot conv_q \cdot dE_{qt} + \sum_{q \in setE} \tau_{qt}^{inv} \cdot ci_{q,t} \cdot dE_{qt}}{p_{Elec,t} \cdot \sum_{q \in setE} dE_{qt}} \qquad \forall t \qquad (F.46)$$

$$\omega_t^D = 1 - \omega_t^F \qquad \forall t \qquad (F.47)$$

$$EC_{i,t}^D = \omega_t^D \cdot p_{Elec,t} \cdot E_{it} + \sum_{q \in setNE} (1 - \tau_{qt}^{fuel}) \cdot cf_{q,t} \cdot dNE_{iqt} \qquad \forall i, t \qquad (F.48)$$

$$EC_{i,t}^F = \omega_t^F \cdot p_{Elec,t} \cdot E_{it} + \sum_{q \in setNE} \tau_{qt}^{fuel} \cdot cf_{q,t} \cdot dNE_{iqt} \qquad \forall i, t \qquad (F.49)$$

F.5 ENVIRONMENT MODULE

$$\begin{aligned} EmissionNE_{CO_2,i,t} = {} & ef_{Coal,CO_2} \cdot (dNE_{i,DomCoal,t} + dNE_{i,ImpCoal,t}) + \\ & ef_{Lignite,CO_2} \cdot dNE_{i,Lignite,t} + \\ & ef_{PetProd,CO_2} \cdot (dNE_{i,DomPetProd,t} + dNE_{i,ImpPetProd,t}) + \\ & ef_{NaturalGas,CO_2} \cdot N_{i,t} \qquad \forall i, t \qquad (F.50) \end{aligned}$$

$$\begin{aligned}EmissionNE_{CH_4,i,t} = & ef_{Coal,CH_4} \cdot dNE_{i,DomesticCoal,t} + \\ & ef_{Lignite,CH_4} \cdot dNE_{i,Lignite,t} + \\ & ef_{Wood,CH_4} \cdot dNE_{i,Wood,t} \qquad \forall i,t \end{aligned} \tag{F.51}$$

$$\begin{aligned}EmissionNE_{N_2O,i,t} = & ef_{Coal,N_2O} \cdot (dNE_{i,DomCoal,t} + dNE_{i,ImpCoal,t}) + \\ & ef_{Lignite,N_2O} \cdot dNE_{i,Lignite,t} + \\ & ef_{PetProd,N_2O} \cdot (dNE_{i,DomPetProd,t} + dNE_{i,ImpPetProd,t}) + \\ & ef_{Wood,N_2O} \cdot dNE_{i,Wood,t} \\ & ef_{NaturalGas,N_2O} \cdot N_{i,t} \qquad \forall i,t \end{aligned} \tag{F.52}$$

$$\begin{aligned}EmissionElec_t = & ef_{Coal,CO_2} \cdot conv_{ImpCoal} \cdot dE_{ImpCoal,t} + ef_{Lign,CO_2} \cdot \sum_{q \in setL} conv_q \cdot dE_{q,t} + \\ & ef_{PetProd,CO_2} \cdot conv_{ImpPetProd} \cdot dE_{ImpPetProd,t} + ef_{NGas,CO_2} \cdot conv_{NGas} \cdot dE_{NGas,t} \\ & ef_{Coal,N_2O} \cdot conv_{ImpCoal} \cdot dE_{ImpCoal,t} + ef_{Lign,N_2O} \cdot \sum_{q \in setL} conv_q \cdot dE_{q,t} + \\ & ef_{PetProd,N_2O} \cdot conv_{ImpPetProd} \cdot dE_{ImpPetProd,t} + ef_{NGas,N_2O} \cdot conv_{NGas} \cdot dE_{NGas,t} \\ & ef_{Lignite,CH_4} \cdot \sum_{q \in setL} conv_q \cdot dE_{q,t} \qquad \forall i,t \end{aligned} \tag{F.53}$$

$$totEmission_{i,t} = Emission_{CO_2,i,t} + Emission_{CH_4,i,t} + Emission_{N_2O,i,t} + EmissionElec_t \cdot \frac{E_{it}}{\sum_{j=1}^{n} E_{jt}} \quad \forall i,t \tag{F.54}$$

APPENDIX G

ENVIRONMENTAL DATA

In this section, we first give a brief information about the GHGs which are taken into account in this study. Then, recent data for GHG emissions published in the annual report for the Turkish GHG inventory, [74], submitted to the Framework Convention on Climate Change is summarized. Finally, calculation of emission factors is explained.

There are six main GHGs those take place in GHG emission tables published in national inventory reports. These are:

- Carbon dioxide, CO_2
- Methane, CH_4
- Nitrous oxide, N_2O
- Hydrofluorocarbons, HFCs
- Perflurocarbons, PFCs
- Sulphur hexafluoride, SF_6

In our study, the first three GHGs in the above list are taken into consideration since the last three account for less than 1% of the total CO_2 equivalent emissions of Turkey. Expressing the emissions in terms of CO_2 equivalent emissions (CO_2e) has been a consensus standart in reporting GHG emissions. In order to convert the GHGs into CO_2e, a measure called Global Warming Potential (GWP) is introduced to the literature. GWP values, which are determined based on radiating force and atmosphere life of the gases, are 1, 21 and 310 for CO_2, CH_4 and N_2O, respectively, [75].

The United Nations Framework Convention on Climate Change (UNFCCC) was ratified by Turkey in 2004 and Turkey prepared its first National Inventory Report (NIR) for the period 1990-2004 in 2006. Table G.1 shows the total CO_2e GHG emissions without Land use Change and Forestry (LUCF) published in the fifth NIR [74] which comprises the data for the period 1990-2008. In our model, only the emissions arising from energy related activities are taken into account since they comprise more than 90% of total emissions. The break-down by sector of CO_2, CH_4 and N_2O emissions can be seen in Table G.2 for the year 2003.

Table G.1: Aggregated CO_2e GHG Emissions without LUCF, Gg, [74].

Year	CO_2	CH_4	N_2O	$HFCs$	$PFCs$	SF_6	Total w/o LUCF
1990	141.36	33.50	11.57	NA	0.60	NA	187.03
1991	148.31	37.56	12.51	NA	0.74	NA	199.13
1992	153.95	41.02	14.58	NA	0.68	NA	210.23
1993	162.55	43.33	15.10	NA	0.69	NA	221.66
1994	160.82	43.71	12.02	NA	0.60	NA	217.15
1995	173.90	46.87	16.22	NA	0.52	NA	237.51
1996	192.01	49.31	16.40	NA	0.52	0.37	258.62
1997	205.18	50.59	14.98	NA	0.52	0.61	271.88
1998	204.32	51.90	16.65	NA	0.52	0.66	274.05
1999	203.68	53.14	16.93	NA	0.51	0.52	274.78
2000	225.43	53.30	16.62	0.82	0.52	0.32	297.01
2001	208.99	52.74	14.69	0.87	0.52	0.31	278.11
2002	217.93	50.43	15.32	1.42	0.52	0.48	286.09
2003	232.64	51.63	15.67	1.81	0.52	0.48	302.75
2004	243.43	49.37	16.00	2.23	0.52	0.70	312.26
2005	259.61	52.35	14.18	2.38	0.49	0.86	329.87
2006	276.72	53.33	15.55	2.73	0.40	0.91	349.64
2007	307.92	55.58	12.35	3.17	C	0.95	379.98
2008	297.12	54.29	11.57	2.67	C	0.84	366.50

Table G.2: Emissions due to Production and Consumption of Energy in 2003, Gg, [74].

	CO_2	CH_4	N_2O
Fuel Combustion (Sectoral Approach)	212.96	2.40	1.35
Energy Industries	74.20	0.03	0.20
Manufacturing Industries and Construction	67.36	0.13	0.24
Transportation	37.77	0.12	0.52
Other Sectors	33.64	2.12	0.38
Other	0.00	NO	NO
Fugitive Emissions From Fuels	0.00	1.29	0.00
Solid Fuels	NE	1.29	NE
Oil and Natural Gas	NE	NE	NE
Total	212.96	3.69	1.35

In order to calculate the energy related CO_2 emissions, the procedure in [76] is followed. The six-step approach in [76] yields the following equation.

$$CO_2\ emission = FC * CC * FOC * CEF * (44/12)/1000 \tag{G.1}$$

where FC is the amount of fuel consumed in ktoe, CC is the ktoe to TJ conversion factor, 41.868, FOC is the fraction of carbon oxidized, CEF is the carbon emission factor and 44/12 is the ratio of molar mass of CO_2 to the atomic mass of carbon. Ultimately, overall expression is divided by 1000 to convert the result into Gg.

Table G.3: Carbon Emission Factors (tC/TJ), [76].

Fuel	Carbon Emission Factor
Coal	25.8
Natural Gas	15.3
Crude Oil	20
Lignite	27.6

Carbon emission factors for coal, natural gas, crude oil and lignite can be seen in G.3. FOC values for coal, petroleum products and natural gas, are 0.98, 0.99 and 0.995, respectively, as presented in [76]. The fraction for lignite is assumed to be the same as it is for coal, i.e., 0.98. Table G.4 illustrates the resulting factors for the CO_2 emitting fuels.

Table G.4: Emission Factors (Gg/ktoe).

Fuel	GHG	Emission Factor
Coal	CO_2	3.881
Petroleum Products	CO_2	3.040
Natural Gas	CO_2	2.337
Lignite	CO_2	4.152

The rest of the emission factors are calibrated using the data in [77]. Main CH_4 emission sources, owing to energy production and use, are fugitive emissions from solid fuels and combustion of plant and animal wastes. Then, emission factors for CH_4 are calculated for coal and lignite production as well as combustion of plant and animal waste which turn out to be 0.1205 Gg/ktoe and 0.3681 Gg/ktoe, respectively. In order to estimate the emission factor for N_2O, total NO_2 emissions are divided by the total primary energy consumption which turns out to be 0.017 Gg/ktoe.

APPENDIX H

COMPUTATIONAL RESULTS

H.1 BASE-CASE SCENARIO

Table H.1: Macroeconomic Variables: BC, 2003 prices, Billions TL.

	2005	2010	2015	2020	2025	2030
GDP	477.61	596.57	759.10	969.19	1239.64	1592.20
Consumption	374.90	459.64	579.16	736.92	936.04	1185.31
Consumption: Domestic	362.34	445.61	561.34	713.81	906.05	1147.83
Consumption: Imported	12.55	14.03	17.82	23.11	29.99	37.48
Consumption: Non-Resident Households	28.32	36.72	51.57	68.28	86.84	109.04
Investments: Total	128.51	182.20	239.78	311.21	405.79	535.90
Investments: Domestic	99.70	143.70	187.68	242.54	316.03	418.80
Investments: Imported	28.81	38.51	52.10	68.67	89.75	117.10
Imports	134.56	185.49	255.81	336.50	428.43	540.06
Exports	115.45	149.70	210.27	278.35	354.05	444.53
Foreign Capital Inflows	19.10	35.79	45.55	58.15	74.38	95.53
Intermediates: Total	441.63	557.55	721.07	919.47	1159.49	1458.52
Intermediates: Domestic	377.89	476.56	615.06	783.85	988.91	1245.34
Intermediates: Imported	63.74	80.99	106.01	135.62	170.58	213.18
Energy Cost: Total	36.14	61.44	94.17	129.90	165.92	205.78
Energy Cost: Domestic	6.69	9.49	14.29	20.79	27.81	33.48
Energy Cost: Imported	29.45	51.96	79.89	109.10	138.11	172.30
Gross Output	927.06	1178.84	1522.77	1950.28	2478.21	3147.47
Capital Stock	1420.62	1913.51	2580.76	3423.74	4493.46	5900.52

H.2 ABATEMENT SCENARIOS: GENERAL

Table H.2: Main Indicators: Abatement Scenarios-General.

Year	BCq20	BCq40	NoNq20	NoNq40	OPq20	OPq40	BCccsQ20	BCccsQ40
GDP, 2003 prices, Billions TL.								
2010	593.08	580.97	592.39	579.89	593.15	581.24	593.36	580.73
2015	744.81	711.57	742.30	708.53	744.97	712.22	745.55	712.39
2020	937.32	876.58	930.48	867.09	937.26	878.05	939.05	878.68
2025	1184.03	1082.41	1164.89	1051.27	1184.59	1087.11	1188.03	1088.15
2030	1511.80	1363.66	1488.59	1325.80	1514.97	1372.26	1515.66	1369.65
GHG emissions, million tones.								
2010	319.04	279.71	316.61	277.82	319.35	280.21	319.92	279.41
2015	399.06	308.41	391.77	304.89	400.99	309.19	399.95	308.91
2020	452.89	328.70	444.08	325.45	457.30	330.89	454.82	328.83
2025	507.22	337.57	518.07	341.62	510.51	337.64	510.02	338.19
2030	670.27	420.04	687.97	430.94	663.98	416.20	661.97	417.98
Primary Energy Consumption, mtoe.								
2010	116.27	105.55	115.57	104.95	116.38	105.72	116.56	105.41
2015	144.69	120.20	142.68	119.06	145.17	120.49	146.01	121.82
2020	170.56	136.28	165.70	132.42	169.99	135.56	173.09	138.21
2025	196.76	149.74	192.48	143.01	195.25	147.67	202.46	155.24
2030	244.60	179.06	242.67	174.81	242.95	177.42	250.45	185.98
Final Energy, mtoe.								
2010	89.73	82.73	89.15	82.20	89.82	82.87	89.98	82.68
2015	110.89	95.16	109.51	94.13	111.15	95.41	111.58	95.38
2020	133.49	109.84	129.67	106.05	132.64	109.06	134.59	110.39
2025	159.26	125.38	151.92	116.83	157.71	123.71	160.94	126.76
2030	193.94	148.60	187.30	140.75	194.26	148.37	195.92	149.56
Electricity, TWh.								
2010	238.20	219.59	237.94	219.52	238.47	219.75	238.38	218.59
2015	326.22	284.77	323.64	284.72	327.39	285.25	327.68	288.36
2020	440.69	389.01	406.02	355.92	420.56	372.71	444.46	397.26
2025	558.97	489.53	486.05	404.82	530.20	463.27	568.27	507.64
2030	660.44	562.23	597.68	488.85	644.78	548.17	671.13	578.36

Table H.3: Main Indicators: Sectoral, BCq30.

	Electricity Mtoe	Natural Gas Mtoe	Petroleum Products Mtoe	Solid Fuels Mtoe	Value-Added Billions TL	GHG Emission Million tons
Agriculture						
2010	0.79	0.00	3.86	0.00	65.24	16.03
2020	1.49	0.00	5.24	0.00	99.81	21.16
2030	2.25	0.00	7.18	0.00	151.36	29.43
Industry: Energy-intensive						
2010	2.79	1.43	4.56	4.02	23.12	48.60
2020	4.90	1.78	5.55	4.80	35.30	57.47
2030	6.86	2.24	6.88	6.31	53.37	75.27
Industry: Other						
2010	6.47	4.68	7.41	7.98	87.48	100.71
2020	11.75	6.12	9.59	10.43	140.31	128.32
2030	17.55	8.19	12.75	15.54	224.87	183.15
Services						
2010	9.66	5.15	3.41	8.84	326.06	89.61
2020	16.53	6.47	4.29	10.72	501.71	107.83
2030	24.97	8.71	5.79	15.81	818.23	164.44
Transportation						
2010	0.17	0.01	15.57	0.00	51.68	48.53
2020	0.34	0.01	22.22	0.00	77.28	69.10
2030	0.53	0.01	31.59	0.00	122.41	98.36
Entire Economy						
2010	19.89	11.26	34.81	20.84	553.58	303.48
2020	35.01	14.38	46.89	25.95	854.41	383.87
2030	52.17	19.15	64.19	37.66	1370.25	550.65

Table H.4: Main Indicators: Sectoral, NoNq30.

	Electricity Mtoe	Natural Gas Mtoe	Petroleum Products Mtoe	Solid Fuels Mtoe	Value-Added Billions TL	GHG Emission Million tons
Agriculture						
2010	0.78	0.00	3.84	0.00	65.30	15.91
2020	1.35	0.00	5.24	0.00	97.30	20.94
2030	1.95	0.00	7.15	0.00	140.54	30.16
Industry: Energy-intensive						
2010	2.79	1.42	4.54	3.98	23.08	48.22
2020	4.38	1.79	5.57	4.71	34.94	56.24
2030	5.94	2.26	6.95	6.17	52.16	77.35
Industry: Other						
2010	6.44	4.66	7.36	7.88	87.11	99.50
2020	10.73	6.14	9.63	10.26	139.45	126.55
2030	15.43	8.20	12.77	15.21	219.64	189.15
Services						
2010	9.63	5.12	3.40	8.75	325.86	88.37
2020	15.39	6.49	4.31	10.60	497.47	106.76
2030	22.57	8.78	5.85	15.40	801.27	176.11
Transportation						
2010	0.17	0.01	15.51	0.00	51.58	48.33
2020	0.31	0.01	21.86	0.00	76.43	67.98
2030	0.47	0.01	30.65	0.00	119.46	95.71
Entire Economy						
2010	19.81	11.21	34.65	20.61	552.93	300.33
2020	32.15	14.42	46.61	25.57	845.59	378.46
2030	46.36	19.25	63.37	36.77	1333.08	568.49

Table H.5: Main Indicators: Sectoral, OPq30.

	Electricity Mtoe	Natural Gas Mtoe	Petroleum Products Mtoe	Solid Fuels Mtoe	Value-Added Billions TL	GHG Emission Million tons
Agriculture						
2010	0.79	0.00	3.87	0.00	65.30	16.09
2020	1.41	0.00	5.30	0.00	97.34	21.31
2030	2.18	0.00	7.25	0.00	142.30	29.07
Industry: Energy-intensive						
2010	2.80	1.43	4.57	4.03	23.14	48.77
2020	4.56	1.80	5.60	4.85	35.23	57.51
2030	6.55	2.28	7.01	6.56	53.96	74.65
Industry: Other						
2010	6.50	4.69	7.43	8.02	87.61	101.15
2020	11.20	6.20	9.71	10.60	140.69	129.83
2030	17.02	8.32	12.93	16.13	226.93	182.21
Services						
2010	9.69	5.15	3.42	8.86	326.11	90.03
2020	16.04	6.55	4.34	10.89	502.52	110.18
2030	24.57	8.76	5.82	16.26	820.69	161.32
Transportation						
2010	0.17	0.01	15.59	0.00	51.71	48.61
2020	0.33	0.01	22.32	0.00	77.42	69.44
2030	0.53	0.01	31.80	0.00	122.79	98.91
Entire Economy						
2010	19.95	11.28	34.87	20.91	553.88	304.65
2020	33.54	14.55	47.27	26.35	853.21	388.27
2030	50.84	19.37	64.81	38.94	1366.67	546.16

Table H.6: Main Indicators: Sectoral, BCccsQ30.

	Electricity Mtoe	Natural Gas Mtoe	Petroleum Products Mtoe	Solid Fuels Mtoe	Value-Added Billions TL	GHG Emission Million tons
Agriculture						
2010	0.78	0.00	3.87	0.00	65.27	16.12
2020	1.52	0.00	5.25	0.00	97.16	21.29
2030	2.32	0.00	7.22	0.00	142.18	29.13
Industry: Energy-intensive						
2010	2.79	1.43	4.57	4.03	23.14	48.89
2020	4.99	1.79	5.58	4.84	35.57	58.05
2030	6.99	2.25	6.90	6.49	53.71	74.64
Industry: Other						
2010	6.46	4.69	7.43	8.01	87.47	101.29
2020	11.99	6.17	9.65	10.51	141.15	129.70
2030	18.01	8.28	12.89	15.98	225.93	182.09
Services						
2010	9.66	5.17	3.43	8.88	326.29	90.56
2020	16.82	6.46	4.29	10.73	502.87	108.78
2030	25.50	8.70	5.78	16.12	821.13	160.35
Transportation						
2010	0.17	0.01	15.59	0.00	51.70	48.61
2020	0.34	0.01	22.37	0.00	77.60	69.59
2030	0.54	0.01	31.87	0.00	123.11	99.09
Entire Economy						
2010	19.87	11.30	34.89	20.93	553.87	305.48
2020	35.67	14.43	47.15	26.09	854.35	387.42
2030	53.36	19.24	64.66	38.59	1366.05	545.30

H.3 ABATEMENT SCENARIOS: SECTORAL

Table H.7: Main Indicators: Abatement Scenarios-Sectoral.

Year	Aq30	IEq30	IOq30	Sq30	Tq30
GDP, 2003 prices, Billions TL.					
2010	595.61	594.51	593.61	594.54	587.63
2015	755.47	751.81	746.80	749.55	731.56
2020	961.32	953.77	940.27	946.58	910.88
2025	1226.51	1213.75	1183.91	1198.06	1139.26
2030	1572.24	1551.43	1502.82	1530.54	1455.63
GHG emissions, million tones.					
2010	330.71	326.02	322.69	324.66	321.39
2015	448.89	432.59	417.09	420.67	425.06
2020	560.02	527.46	498.21	493.52	516.45
2025	683.50	634.85	571.60	567.57	615.98
2030	872.44	798.95	733.59	742.97	790.26
Primary Energy Consumption, mtoe.					
2010	120.19	118.78	117.83	118.54	116.83
2015	159.36	154.62	150.37	151.83	151.09
2020	200.22	191.24	183.75	183.30	185.26
2025	242.98	230.08	215.53	215.62	220.01
2030	298.85	281.04	263.22	268.17	270.50
Final Energy, mtoe.					
2010	93.11	91.90	91.12	91.70	90.23
2015	121.01	117.64	115.14	116.61	113.92
2020	152.42	146.79	142.91	143.74	139.66
2025	187.57	179.88	173.66	175.06	168.02
2030	227.27	218.64	208.33	213.03	203.85
Electricity, TWh.					
2010	240.29	239.15	238.59	239.49	237.97
2015	352.22	342.40	332.78	332.44	346.33
2020	498.38	477.84	458.78	451.14	487.39
2025	633.70	606.57	578.89	571.21	616.48
2030	745.23	714.37	676.23	682.71	720.31

Table H.8: Main Indicators: Sectoral, Aq30.

	Electricity Mtoe	Natural Gas Mtoe	Petroleum Products Mtoe	Solid Fuels Mtoe	Value-Added Billions TL	GHG Emission Million tons
Agriculture						
2010	0.69	0.00	3.53	0.00	64.63	14.64
2020	1.15	0.00	4.52	0.00	97.71	19.67
2030	1.72	0.00	6.14	0.00	146.72	28.08
Industry: Energy-intensive						
2010	2.91	1.51	4.79	4.71	23.54	53.17
2020	6.68	2.19	6.59	7.89	39.63	90.53
2030	9.25	2.98	8.75	11.08	60.53	128.11
Industry: Other						
2010	6.76	4.92	7.83	9.60	89.70	111.45
2020	14.24	7.07	10.85	16.52	152.30	190.10
2030	21.33	10.09	15.20	25.48	246.72	293.23
Services						
2010	10.12	5.52	3.65	10.10	328.68	100.75
2020	20.37	7.20	4.66	16.22	522.21	178.60
2030	31.10	10.82	6.91	26.27	878.14	298.66
Transportation						
2010	0.18	0.01	16.25	0.00	52.44	50.69
2020	0.43	0.01	25.82	0.00	82.66	81.11
2030	0.69	0.02	39.45	0.00	135.20	124.36
Entire Economy						
2010	20.67	11.96	36.06	24.41	559.00	330.71
2020	42.86	16.47	52.45	40.64	894.51	560.02
2030	64.09	23.90	76.45	62.83	1467.31	872.44

Table H.9: Main Indicators: Sectoral, IEq30.

	Electricity Mtoe	Natural Gas Mtoe	Petroleum Products Mtoe	Solid Fuels Mtoe	Value-Added Billions TL	GHG Emission Million tons
Agriculture						
2010	0.83	0.00	4.15	0.00	65.36	17.32
2020	1.97	0.00	6.13	0.00	99.03	28.31
2030	2.97	0.00	9.13	0.00	148.40	42.15
Industry: Energy-intensive						
2010	2.72	1.36	4.49	3.77	23.06	46.93
2020	4.62	1.74	5.56	4.12	37.09	59.65
2030	6.63	2.25	7.07	4.67	57.08	77.15
Industry: Other						
2010	6.73	4.90	7.76	9.52	89.11	110.90
2020	14.17	7.06	10.81	16.58	151.76	187.14
2030	20.83	9.92	14.93	25.55	240.99	277.31
Services						
2010	10.11	5.52	3.62	10.02	328.40	100.28
2020	19.91	7.20	4.64	16.30	519.01	172.22
2030	30.32	10.74	6.84	27.00	869.32	279.57
Transportation						
2010	0.18	0.01	16.22	0.00	52.38	50.58
2020	0.42	0.01	25.55	0.00	81.81	80.14
2030	0.68	0.02	39.09	0.00	133.70	122.77
Entire Economy						
2010	20.57	11.79	36.24	23.31	558.31	326.02
2020	41.09	16.01	52.69	37.00	888.70	527.46
2030	61.44	22.92	77.06	57.23	1449.49	798.95

Table H.10: Main Indicators: Sectoral, IOq30.

	Electricity Mtoe	Natural Gas Mtoe	Petroleum Products Mtoe	Solid Fuels Mtoe	Value-Added Billions TL	GHG Emission Million tons
Agriculture						
2010	0.84	0.00	4.15	0.00	65.33	17.33
2020	1.83	0.00	6.11	0.00	97.75	26.97
2030	2.72	0.00	8.86	0.00	143.11	38.93
Industry: Energy-intensive						
2010	2.91	1.51	4.75	4.69	23.33	53.19
2020	6.73	2.31	6.91	8.61	41.27	92.72
2030	9.22	3.08	9.04	12.42	61.91	127.93
Industry: Other						
2010	6.52	4.54	7.44	7.75	88.08	100.19
2020	11.61	6.04	9.68	9.37	141.19	133.15
2030	17.09	8.06	12.75	11.88	220.20	180.73
Services						
2010	10.08	5.56	3.59	10.40	328.54	101.48
2020	18.89	7.34	4.69	17.09	516.01	166.26
2030	28.50	10.76	6.82	28.32	850.81	266.52
Transportation						
2010	0.18	0.01	16.19	0.00	52.32	50.50
2020	0.40	0.01	25.29	0.00	81.07	79.11
2030	0.63	0.01	38.17	0.00	130.38	119.48
Entire Economy						
2010	20.52	11.62	36.13	22.84	557.60	322.69
2020	39.45	15.71	52.68	35.07	877.29	498.21
2030	58.16	21.92	75.64	52.62	1406.41	733.59

Table H.11: Main Indicators: Sectoral, Sq30.

	Electricity Mtoe	Natural Gas Mtoe	Petroleum Products Mtoe	Solid Fuels Mtoe	Value-Added Billions TL	GHG Emission Million tons
Agriculture						
2010	0.83	0.00	4.14	0.00	65.20	17.27
2020	1.82	0.00	6.25	0.00	98.67	27.06
2030	2.78	0.00	9.34	0.00	147.87	40.42
Industry: Energy-intensive						
2010	2.94	1.53	4.77	4.71	23.62	53.33
2020	6.03	2.19	6.56	7.97	38.63	83.28
2030	8.63	3.06	8.95	11.99	60.84	119.62
Industry: Other						
2010	6.81	5.04	7.80	9.60	89.86	112.00
2020	13.42	7.26	10.98	16.96	150.47	179.12
2030	20.57	10.58	15.82	27.78	249.79	278.52
Services						
2010	9.83	5.08	3.46	8.72	327.07	91.43
2020	17.14	6.60	4.46	10.30	512.95	124.65
2030	26.12	9.14	6.14	13.39	837.56	185.24
Transportation						
2010	0.18	0.01	16.24	0.00	52.19	50.64
2020	0.39	0.01	25.42	0.00	80.50	79.42
2030	0.62	0.01	38.12	0.00	129.07	119.18
Entire Economy						
2010	20.60	11.66	36.41	23.04	557.94	324.66
2020	38.80	16.06	53.66	35.23	881.22	493.52
2030	58.71	22.80	78.37	53.15	1425.12	742.97

Table H.12: Main Indicators: Sectoral, Tq30.

	Electricity Mtoe	Natural Gas Mtoe	Petroleum Products Mtoe	Solid Fuels Mtoe	Value-Added Billions TL	GHG Emission Million tons
Agriculture						
2010	0.83	0.00	4.15	0.00	65.15	17.31
2020	2.06	0.00	6.01	0.00	97.76	28.77
2030	3.07	0.00	8.89	0.00	145.26	43.54
Industry: Energy-intensive						
2010	2.88	1.49	4.72	4.64	23.26	52.48
2020	6.42	2.06	6.22	7.43	38.07	85.84
2030	8.87	2.75	8.12	10.45	58.38	120.62
Industry: Other						
2010	6.63	4.83	7.68	9.36	87.64	109.14
2020	13.94	6.72	10.33	15.64	145.63	182.30
2030	21.40	9.84	14.82	25.32	245.07	289.88
Services						
2010	9.98	5.41	3.58	10.03	325.30	99.28
2020	19.26	6.66	4.32	14.93	491.35	165.07
2030	28.26	9.55	6.11	23.43	790.62	265.18
Transportation						
2010	0.14	0.00	13.86	0.00	50.66	43.19
2020	0.24	0.01	17.42	0.00	75.35	54.46
2030	0.35	0.01	22.63	0.00	117.04	71.04
Entire Economy						
2010	20.47	11.73	34.00	24.03	552.00	321.39
2020	41.92	15.44	44.31	37.99	848.16	516.45
2030	61.95	22.14	60.56	59.20	1356.38	790.26

H.4 PRICE SCENARIOS

Table H.13: Main Indicators: Price Scenarios.

Year	BC-low	BC-high
GDP, 2003 prices, Billions TL.		
2010	598.21	596.43
2015	770.90	757.00
2020	993.15	959.90
2025	1280.29	1221.56
2030	1661.82	1558.66
GHG emissions, million tones.		
2010	338.66	333.08
2015	470.56	457.22
2020	610.62	577.76
2025	770.28	699.12
2030	1011.23	895.28
Primary Energy Consumption, mtoe.		
2010	122.89	120.53
2015	166.56	161.15
2020	216.08	204.06
2025	269.74	246.09
2030	340.67	302.87
Final Energy, mtoe.		
2010	94.98	93.42
2015	126.17	121.89
2020	163.44	153.90
2025	206.04	188.27
2030	254.20	227.12
Electricity, TWh.		
2010	248.33	240.24
2015	368.03	357.48
2020	531.36	511.90
2025	686.83	648.23
2030	841.75	770.81

Table H.14: Main Indicators: Sectoral, BC-low.

	Electricity Mtoe	Natural Gas Mtoe	Petroleum Products Mtoe	Solid Fuels Mtoe	Value-Added Billions TL	GHG Emission Million tons
Agriculture						
2010	0.86	0.00	4.14	0.00	65.24	17.50
2020	2.14	0.00	6.41	0.00	101.39	30.99
2030	3.44	0.00	10.07	0.00	156.74	51.07
Industry: Energy-intensive						
2010	3.02	1.58	4.78	4.73	23.84	54.04
2020	6.59	2.47	6.45	7.95	40.34	92.28
2030	9.68	3.48	8.93	11.39	64.06	138.21
Industry: Other						
2010	6.96	5.20	7.77	9.62	90.35	113.39
2020	15.12	8.51	11.13	17.73	160.96	207.24
2030	24.05	12.66	16.56	28.61	271.38	341.90
Services						
2010	10.33	5.77	3.59	10.06	329.42	102.59
2020	21.38	8.48	4.73	17.12	539.84	195.85
2030	34.46	13.02	7.26	27.79	923.17	347.04
Transportation						
2010	0.19	0.01	16.38	0.00	52.45	51.13
2020	0.46	0.01	26.75	0.00	84.07	84.26
2030	0.76	0.02	42.03	0.00	139.10	133.01
Entire Economy						
2010	21.36	12.56	36.66	24.41	561.30	338.66
2020	45.70	19.47	55.47	42.80	926.60	610.62
2030	72.39	29.17	84.85	67.79	1554.44	1011.23

Table H.15: Main Indicators: Sectoral, BC-high.

	Electricity Mtoe	Natural Gas Mtoe	Petroleum Products Mtoe	Solid Fuels Mtoe	Value-Added Billions TL	GHG Emission Million tons
Agriculture						
2010	0.82	0.00	4.11	0.00	65.23	17.17
2020	2.04	0.00	5.94	0.00	99.00	29.00
2030	3.14	0.00	8.56	0.00	148.55	44.00
Industry: Energy-intensive						
2010	2.89	1.51	4.74	4.71	23.50	53.03
2020	6.76	2.20	6.42	8.01	39.84	92.44
2030	9.59	2.99	8.29	11.24	61.24	131.99
Industry: Other						
2010	6.72	4.92	7.74	9.63	89.69	111.48
2020	14.53	7.10	10.52	16.71	152.89	195.25
2030	21.91	9.94	14.08	25.45	246.03	298.54
Services						
2010	10.05	5.55	3.62	10.15	328.94	101.22
2020	20.25	7.11	4.45	15.92	516.20	180.74
2030	30.89	10.35	6.21	25.04	857.97	298.22
Transportation						
2010	0.18	0.01	16.08	0.00	52.43	50.18
2020	0.45	0.01	25.49	0.00	82.85	80.34
2030	0.76	0.02	38.66	0.00	135.12	122.54
Entire Economy						
2010	20.66	11.98	36.30	24.48	559.79	333.08
2020	44.02	16.42	52.82	40.64	890.79	577.76
2030	66.29	23.29	75.81	61.73	1448.91	895.28

H.5 DOMESTIC AND FOREIGN ENERGY COSTS

Figure H.1 displays the share of foreign energy cost in total imports for BC, BCq30, OP, NoN, BC-high and BC-low. As seen in this figure the share of energy costs significantly increase throughout the planning horizon for in of the scenarios. As expected, it is the BC-high scenario in which this share increases at most. Note that the sharp increase in 2008 is due to the sharp increase in world energy prices in the given year.

Figure H.2, on the other hand, shows the share of domestic component of energy cost in total energy cost for the same scenarios. This figure indicates that it is the BC-low scenario in which the share of domestic component of energy cost is highest among all scenarios. Besides this, low share in BCq30 scenario implies that the decrease in consumption of domestic energy resources is more than the decrease in foreign energy consumption under emission quotas.

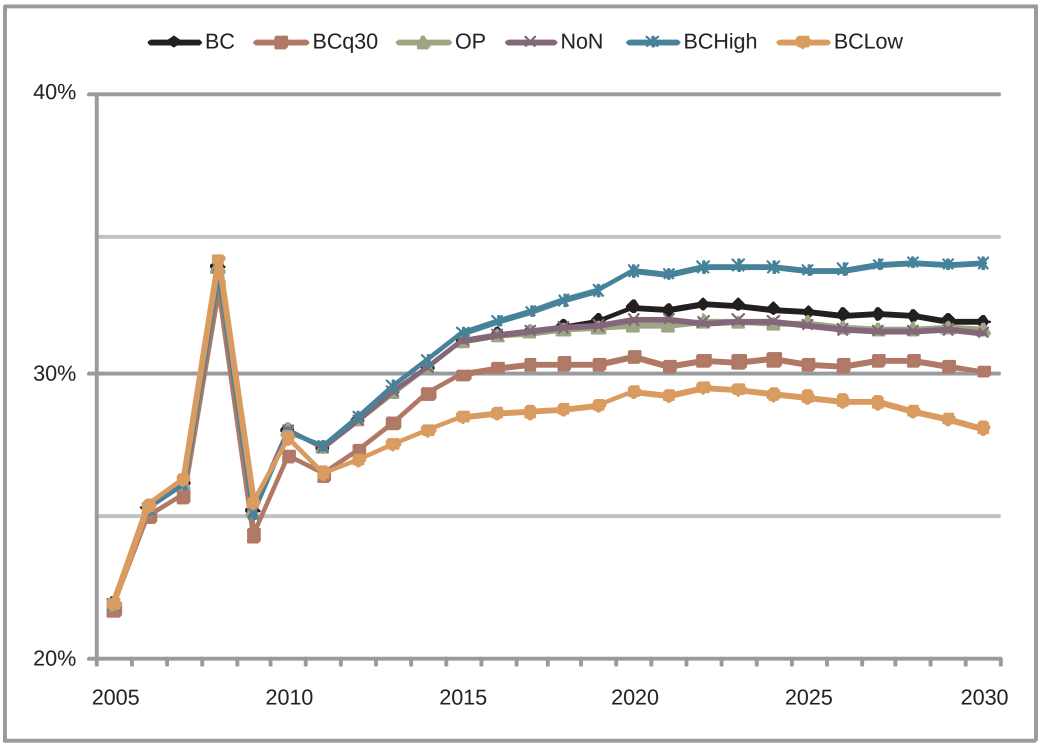

Figure H.1: Share of Foreign Energy Costs in Total Imports.

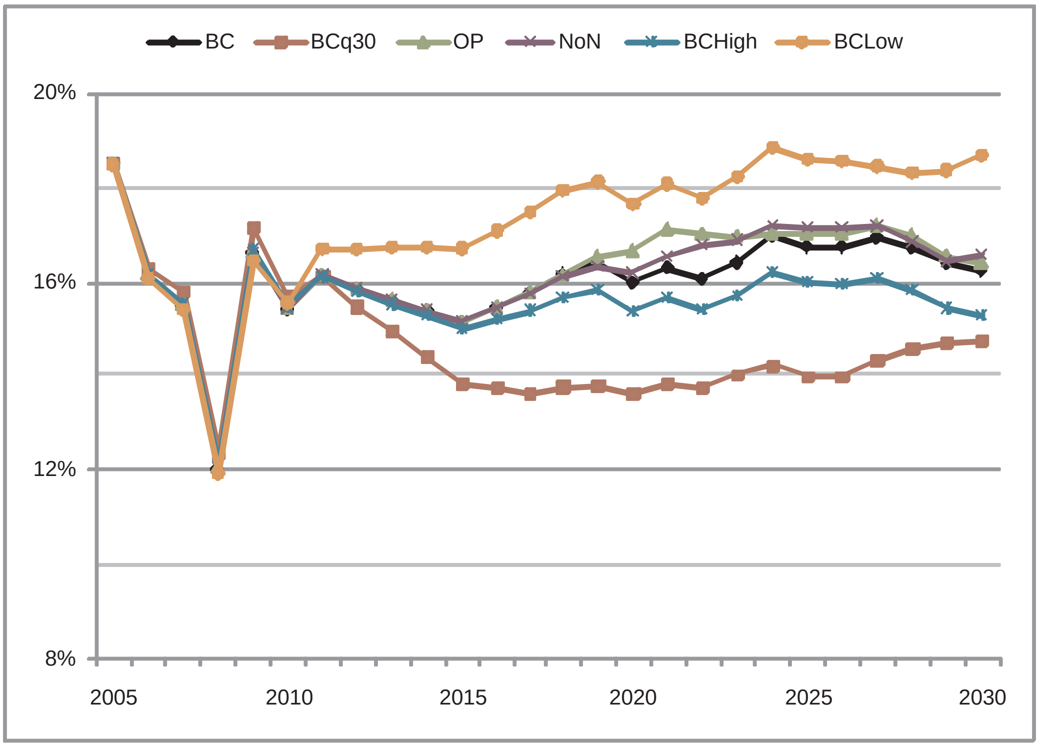

Figure H.2: Share of Domestic Energy Costs in Total Energy Costs.

APPENDIX I

GAMS CODE

```
$OFFSYMLIST OFFSYMXREF OFFUPPER
*==================================================================
$TITLE MULTI-SECTOR OPEN ECONOMY GENERAL EQUILIBRIUM MODEL FOR TURKEY
*==================================================================
$ontext
```

Programmed by: Bora Kat

Economy is disaggregated into five main sectors. Gross Output of sector i, $[Y_i]$, includes $[VA_i]$, Intermediates$[INT_i]$ and Energy Costs $[EC_i]$. The planning Horizon is 2003-2030 where the base year is 2003. The model is run for the period 2003-2040 in order to reduce the end of horizon effects. Production is assumed to take place according to a putty-clay technology. That is, the economy-wide production function allows substitution among inputs only for the increments in the factors, whereas surviving stocks are assumed to remain unchanged.

Production Function: Multi-level CES Technology

Aggregation of capital and labor → Cobb-Douglas Function

Aggregation of Elec., Pet. Prod*s*, Nat. Gas and Solid Fuels → Cobb-Douglas Function

Aggregation of Capital-Labor and Energy Aggregates → CES Technology

Intermediates : Determined using the base year ratios: $Int_t = Coef(base) * Y_t$

```
*==================================================================
```

Units:

Energy ktoe

Money 10^{12} TL, 2003

```
$offtext
```

```
*============================================================================
SETS
*============================================================================

tdum       Planning Horizon                                   /2003*2040/
t(tdum)    Planning Horizon                                   /2003*2040/
*dummy set to run the model for shorter planning horizons
t0(t)      Base Year                                          /2003/
tlast(t)   Last Year                                          /2040/

i0         Sectors including whole                            /Whole
                                                              Agriculture
                                                              IndHighEn
                                                              IndOth
                                                              Services
                                                              Transport/

i(i0)      Sectors                                            /Agriculture
                                                              IndHighEn
                                                              IndOth
                                                              Services
                                                              Transport/

r          All Energy Resources                               /Hydro
                                                              HydroDAM
                                                              HydroRIVER
                                                              PetroleumProducts
                                                              NaturalGas
                                                              Coal
                                                              Lignite
                                                              Lignite1
                                                              Lignite2
                                                              Lignite3
                                                              Wood
                                                              Renewables
                                                              Geothermal
                                                              Wind
                                                              Solar
                                                              Nuclear/

ee(r)      Electricity generation options                     /Hydro
                                                              HydroDAM
                                                              HydroRIVER
                                                              PetroleumProducts
                                                              NaturalGas
                                                              Coal
                                                              Lignite
                                                              Lignite1
                                                              Lignite2
                                                              Lignite3
                                                              Renewables
                                                              Geothermal
                                                              Wind
                                                              Solar
                                                              Nuclear/

ee2(ee)    Electricity generation options                     /HydroDAM
                                                              HydroRIVER
                                                              PetroleumProducts
```

```
                                                        NaturalGas
                                                        Coal
                                                        Lignite1
                                                        Lignite2
                                                        Lignite3
                                                        Renewables
                                                        Geothermal
                                                        Wind/

ne(r)    Inputs for non-electric energy                 /PetroleumProducts
                                                        NaturalGas
                                                        Coal
                                                        Lignite
                                                        Wood
                                                        Renewables/

sne(r)   Solid fuels for non-electricity use            /Coal
                                                        Lignite
                                                        Wood/

de(r)    Domestic energy resources                      /Hydro
                                                        HydroDAM
                                                        HydroRIVER
                                                        PetroleumProducts
                                                        Coal
                                                        Lignite
                                                        Lignite1
                                                        Lignite2
                                                        Lignite3
                                                        Wood
                                                        Renewables/

fe(r)    Foreign energy resources                       /PetroleumProducts
                                                        Coal
                                                        NaturalGas
                                                        Nuclear/

g        Greenhouse gases                               /Whole
                                                        CO2
                                                        CH4
                                                        N2O/

;

 alias (i,j)
 alias (i,ii)
 alias (i,jj)
 alias (t,tt)

*=====================================================================
PARAMETERS
*=====================================================================

Y0(i0)          Gross Output in Sector i in base year

VA0(i)          Value Added in Sector i in base year
```

K0(i)	Capital stock in Sector i in base year	/Agriculture	60481.595
		IndHighEn	52100.543
		IndOth	214772.191
		Services	698023.697
		Transport	280496.943/

*K0 values are determined using the data in Saygili, Cihan Yurtoglu. First, shares of sectoral capital stock values in 2003 are determined, then 3*GDP(2003) is distributed among the sectors based on the calculated shares.

EC0(i0)	Energy Costs in sector i in the base year		
ECD0(i0)	Domestic Energy Costs in sector i in the base year		
ECF0(i0)	Foreign Energy Costs in sector i in the base year		
C0(i0)	Consumption of good i in the base year: private+government		
		/Whole	368895.465
		Agriculture	29165.154
		IndHighEn	8974.930
		IndOth	92426.653
		Services	201863.101
		Transport	36465.628/
CGF0(i0)	Consumption of good i in the base year: Imports	/Whole	11023.138
		Agriculture	324.323
		IndHighEn	2473.309
		IndOth	6606.214
		Services	1492.347
		Transport	126.945/
CGD0(i0)	Consumption of good i in the base year: Domestic		
		/Whole	357872.328
		Agriculture	28840.831
		IndHighEn	6501.621
		IndOth	85820.439
		Services	200370.754
		Transport	36338.683/
X0(i0)	Exports of good i in the base year	/Whole	0.000
		Agriculture	2886.563
		IndHighEn	9428.279
		IndOth	42425.178
		Services	16092.490
		Transport	7895.938/
M0(i0)	Imports of good i in the base year	/Whole	0.000
		Agriculture	3278.357
		IndHighEn	29280.771
		IndOth	49882.000
		Services	3918.545
		Transport	3970.455/

TABLE Inter0(i,j) Intermediates matrix in the base year

	Agriculture	IndHighEn	IndOth	Services	Transport
Agriculture	10697.039	560.740	28700.710	3693.631	31.414
IndHighEn	2621.966	19272.075	30524.537	19078.930	482.604
IndOth	3820.266	7731.918	78191.692	34548.879	4794.640
Services	5156.132	8265.362	32076.723	81830.473	17713.134
Transport	1146.067	2880.123	10339.733	13900.774	7640.008

;

TABLE InterD0(i,j) Intermediates matrix in the base year-Domestic

	Agriculture	IndHighEn	IndOth	Services	Transport
Agriculture	10393.883	389.328	26404.706	3524.122	31.382
IndHighEn	1975.392	11467.149	16462.384	14808.691	459.034
IndOth	3464.727	6395.146	61766.935	28454.076	3542.494
Services	5042.192	8053.009	31686.636	80374.216	17490.242
Transport	1132.862	2816.382	10190.847	11610.727	6312.377

;

TABLE InterF0(i,j) Intermediates matrix in the base year-Foreign

	Agriculture	IndHighEn	IndOth	Services	Transport
Agriculture	303.156	171.412	2296.004	169.509	0.031
IndHighEn	646.573	7804.926	14062.153	4270.239	23.570
IndOth	355.538	1336.772	16424.757	6094.803	1252.146
Services	113.940	212.353	390.087	1456.257	222.892
Transport	13.206	63.741	148.886	2290.047	1327.631

;

TABLE Invest0(i,j) Investment matrix in base year

	Agriculture	IndHighEn	IndOth	Services	Transport
Agriculture	1.461	1.259	5.189	16.864	6.777
IndHighEn	0.065	0.056	0.231	0.749	0.301
IndOth	1488.522	1282.255	5285.792	17179.171	6903.354
Services	1993.946	1717.641	7080.568	23012.310	9247.369
Transport	99.234	85.483	352.384	1145.271	460.221

;

TABLE InvestD0(i,j) Investment matrix in the base year-Domestic

	Agriculture	IndHighEn	IndOth	Services	Transport
Agriculture	0.816	0.703	2.899	9.422	3.786
IndHighEn	0.065	0.056	0.231	0.749	0.301
IndOth	663.570	571.618	2356.360	7658.323	3077.455
Services	1992.525	1716.417	7075.524	22995.917	9240.781
Transport	99.234	85.483	352.384	1145.271	460.221

;

TABLE InvestF0(i,j) Investment matrix in the base year-Foreign

	Agriculture	IndHighEn	IndOth	Services	Transport
Agriculture	0.645	0.555	2.290	7.441	2.990
IndHighEn	0.000	0.000	0.000	0.000	0.000
IndOth	824.952	710.637	2929.433	9520.848	3825.900
Services	1.420	1.224	5.044	16.394	6.588
Transport	0.000	0.000	0.000	0.000	0.000

;

PARAMETERS
*==
*Base Year Energy Data
*==

E0(i0) Electricity Demand in sector i in the base year-ktoe

/Whole	12138.986
Agriculture	410.922
IndHighEn	1950.199
IndOth	3821.204
Services	5856.927
Transport	99.733/

P0(i0) Petroleum Demand in sector i in the base year-ktoe

/Whole	27682.785
Agriculture	2771.534
IndHighEn	4031.391
IndOth	5835.822
Services	2728.982
Transport	12315.057/

S0(i0) Solid Fuels Demand in sector i in the base year-ktoe

/Whole	18012.630
Agriculture	0.001
IndHighEn	3630.266
IndOth	6618.832
Services	7763.532
Transport	0.001/

N0(i0) Natural Gas Demand in sector i in the base year-ktoe

/Whole	7888.366
Agriculture	0.001
IndHighEn	1148.028
IndOth	3212.243
Services	3524.136
Transport	3.959/

COALD0(i0) Dom. coal consumption for non-electric use in sector i in the base year-ktoe

/Whole	1054.972
Agriculture	0.001
IndHighEn	370.168
IndOth	593.997
Services	90.807
Transport	0.001/

COALF0(i0) Foreign coal cons. for non-electric use in sector i in the base year-ktoe

/Whole	7858.299
Agriculture	0.001
IndHighEn	2757.316
IndOth	4424.582
Services	676.402
Transport	0.001/

PETD0(i0) Dom. pet. products cons. for non-electric use in sector i in the base year-ktoe

/Whole	2173.269
Agriculture	217.582
IndHighEn	316.489
IndOth	458.148
Services	214.242
Transport	966.808/

PETF0(i0) Foreign pet.-prod. cons. for non-electric use in sector i in the base year-ktoe

/Whole	25509.516
Agriculture	2553.952
IndHighEn	3714.902
IndOth	5377.674
Services	2514.740
Transport	11348.249/

LIGN0(i0) Lignite consumption for non-electric use in sector i in the base year-ktoe

/Whole	3351.089
Agriculture	0.001
IndHighEn	502.782
IndOth	1600.253
Services	1248.054
Transport	0.001/

LIGN1_0	Lign. 1 cons. for non-elec. use in the base year-ktoe	/ 3351.089/
LIGN2_0	Lign. 2 cons. for non-elec. use in the base year-ktoe	/ 0.000/
LIGN3_0	Lign. 3 cons. for non-elec. use in the base year-ktoe	/ 0.000/

WOOD0(i0) Wood consumption for non-elec. use in the base year-ktoe

/Whole	5748.270
Agriculture	0.001
IndHighEn	0.001
IndOth	0.001
Services	5748.270
Transport	0.001/

TotLign0	Tot. lign. cons. -for elec. and non-elec.-ktoe-base year.	/ 9713.204/
TotLign1_0	Tot. lign. 1 cons. -for elec. and non-elec-ktoe-base year	/ 7176.105/
TotLign2_0	Tot. lign. 2 cons. -for elec. and non-elec. -ktoe-base year	/ 1320.794/
TotLign3_0	Tot. lign. 3 cons. -for elec. and non-elec. -ktoe-base year	/ 1216.305/
TotPetF0	Tot. Foreign Pet. Prod. cons. -for elec. and non-elec. -ktoe-base year.	/ 27710.546/
TotCoalF0	Tot. Foreign Coal cons. -for elec. and non-elec. -ktoe-base year.	/ 9632.079/
TotNG0	Tot. Natural Gas cons. -for elec. and non-elec. -ktoe-base year.	/ 19226.344/

```
EPET0           Elec. Prod. By Pet. Prod. Plants-ktoe-base year.                    /    790.873/
ECOAL0          Elec. Prod. By Hard-Coal Plants-ktoe-base year.                     /    745.018/
ENGAS0          Elec. Prod. By Natural Gas Plants-ktoe-base year.                   /   5464.096/

EREN0           Elec. Prod. By Renewables-ktoe-base year.                           /     81.476/
EGEO0           Elec. Prod. By Geothermal-ktoe-base year.                           /     76.196/
EWND0           Elec. Prod. By Wind-ktoe-base year.                                 /      5.280/
ESOL0           Elec. Prod. By Solar-ktoe-base year.                                /      1.000/

ENUC0           Elec. Prod. By Nuclear Plants-ktoe-base year.                       /      1.000/

EHYDR0          Elec. Prod. By Hydro Power Plants-ktoe-base year.                   /   3038.332/
EHYDRODAM0          Elec. Prod. By DAMs-ktoe-base year.                             /   2826.211/
EHYDRORIVER0        Elec. Prod. By Run of RIVER-ktoe-base year.                     /    212.120/


ELIGN0          Elec. Prod. By Lign. Pow. Plants-ktoe-base year.                    /   2038.699/
ELIGN1_0        Elec. Prod. By Lign. 1 Pow. Plants-ktoe-base year.                  /   1238.911/
ELIGN2_0        Elec. Prod. By Lign. 2 Pow. Plants-ktoe-base year.                  /    382.939/
ELIGN3_0        Elec. Prod. By Lign. 3 Pow. Plants-ktoe-base year.                  /    416.848/

;

SCALARS


F0              Foreign capital inflows in the base year                            /   4576.253/
NRH0            Fin. Cons. Exp. of Non-Res HHs on the Economic Territory-base year  / 24852.807/
GDP0            Gross Domestic Product in the base year

er0             Exchange rate in the base year                                      /      1.000/
delt            Utility discount factor                                             /      0.100/

EF_N2O          Emission factor for N2O


pelec0          Average price of electricity in the base year
plign0          Average price of lignite in the base year

DomElecCoef0    Share of domestic costs in total cost of generating electricity
ForElecCoef0    Share of foreign costs in total cost of generating electricity

td              Coefficicient for transmission-distribution-Elec                       /   1.200/
dGas            Coefficicient for distribution-Natural Gas                             /   1.000/

icL             Lower bound coefficient-investments
icU             Upper bound coefficient-investments

XMcL            Lower bound coefficient-eXports-iMports
XMcU            Upper bound coefficient-eXports-iMports

;
```

```
*===========================================================================
PARAMETERS
*===========================================================================

L0(i0,tdum)      Labor in year t in sector i


lambda(i)        Rate of decline of stocks due to retirement            /Agriculture     0.970
                                                                         IndHighEn       0.970
                                                                         IndOth          0.970
                                                                         Services        0.970
                                                                         Transport       0.970/

klambda(i)       Rrate of decline of stocks due to retirement-capital   /Agriculture     0.960
                                                                         IndHighEn       0.960
                                                                         IndOth          0.960
                                                                         Services        0.965
                                                                         Transport       0.960/

llambda(i)       Rate of decline of stocks due to retirement-labor      /Agriculture     0.970
                                                                         IndHighEn       0.970
                                                                         IndOth          0.970
                                                                         Services        0.970
                                                                         Transport       0.970/

cd(de,tdum)      Fuel cost of domestic resource de
cf(fe,tdum)      Fuel cost of imported resource fe
ce(ee,tdum)      Operation & Maintenance cost in power plant of type ee
ci(ee,tdum)      Annualized investment cost per ktoe for power station of type ee

DepF(ee,tdum)    Coefficient to calculate depreciation of initial installed capacity

ppet0(i)         Average price of petroleum products in sector i-base year
psol0(i)         Average price of solid fuels in sector i-base year
penergy0(i)      Average price of energy for sector i-base year

Conv(r)          Conversion factor- amount of fuel r required to generate one unit of electricity

Rsrv(r)          Reserve of resource r

IncLow(ee,t)     Incremental capacity ratio for power plant in year t-Low
IncUp(ee,t)      Incremental capacity ratio for power plant in year t -Up

delta(t)         Compounded discount factor in year t
pgr              Post-horizon growth rate                                             /    0.030/

XtoVA(i)         Exports to VA ratio in sector i
MtoVA(i)         Imports to VA ratio in sector i

NRHtoX           NRH to exports ratio

er(t)            Exchange rate in year t
EF(r,g)          Emmission Factor- of type g & of resource r
fc(t)            Foreign capital inflow to GDP ratio
```

```
*=========================================================================
ResultsMain(*,*)                    Results- Main Variables
ResultsROC(*,*)                     Results- Return on Capital
ResultsGrowth(*,*)                  Results- Growth Rates of Main Variables
ResultsFinalEnergy(*,*)             Results- Final Energy
ResultsFinalEnergyComp(*,*)         Results- Final Energy Composition
ResultsElec(*,*)                    Results- Electricity
ResultsElecComp(*,*)                Results- Electricity Composition
ResultsPrimaryEnergy(*,*)           Results- Primary Energy
ResultsPrimaryEnergyComp(*,*)       Results- Primary Energy Composition
ResultsSecFinalEnergyComp(*,*,*)    Results- Final Energy Composition-Sectoral
ResultsGHG(*,*,*)                   Results- GHG
ResultsMacro(*,*)                   Results- Macro Variables
ResultsMacroSec(*,*,*)              Results- Macro Variables-Sectoral
ResultsElecPrice(*,*)               Results- Electricity Price c per kwh
*=========================================================================

IncLow(ee,t)                        = 0.00;
IncUp(ee,t)                         = 0.20;
IncUp("HydroDAM",t)                 = 0.10;
IncUp("HydroRIVER",t)               = 0.10;

Loop(t$(ord(t)<=8),IncUp("HydroDAM",t)=0.05);
Loop(t$(ord(t)<=8),IncUp("HydroRIVER",t)=0.05);
Loop(t$(ord(t)<=28),IncLow("NaturalGas",t)=0.000);
Loop(t$(ord(t)<=18),IncLow("NaturalGas",t)=0.040);
Loop(t$(ord(t)<=13),IncLow("NaturalGas",t)=0.075);
Loop(t$(ord(t)<=13),IncUp("Wind",t)=0.25);
Loop(t$(ord(t)<=8),IncUp("Wind",t)=1);
Loop(t$((ord(t)>=4)AND(ord(t)<=8)),IncUp("Lignite1",t)=0.10);
Loop(t$((ord(t)>=4)AND(ord(t)<=8)),IncUp("Lignite2",t)=0.10);
Loop(t$((ord(t)>=4)AND(ord(t)<=8)),IncUp("Lignite3",t)=0.10);
Loop(t$((ord(t)>=4)AND(ord(t)<=8)),IncUp("Coal",t)=0.10);
IncUp("Solar",t)                    = 10000;
IncUp("Nuclear",t)                  = 10000;
Loop((ee,t)$((ord(t)<4)),IncUp(ee,t)=0.40);
Loop((ee,t)$((ord(t)<4)),IncLow(ee,t)=0.00);

*=========================================================================
Rsrv("Lignite")                     = 1640000;
Rsrv("Lignite1")                    =   640000;
Rsrv("Lignite2")                    =   360000;
Rsrv("Lignite3")                    =   640000;
Rsrv("PetroleumProducts")           =     71234.940;
Rsrv("Hydro")                       =     10954;
Rsrv("HydroDam")                    =     10350.513;
Rsrv("HydroRiver")                  =         776.855;
Rsrv("Geothermal")                  =         330.240;
Rsrv("Coal")                        =   355420.800;
Rsrv("Wind")                        =       4000;
Rsrv("Solar")                       =     34400;
*=========================================================================

delta(t)          = (1/(1+delt))**(ord(t)-1);
icL               = 1/2;
icU               = 3/2;
XMcL              = 0.95;
XMcU              = 1.05;
```

```
*============================================================================
*Reading Cost Parameters
*============================================================================

$include 'C:\Users\dell\Documents\Doktora\Tez.Modeller.Defense\Two.Sector\IncludeFiles\CD_Coal.inc'
$include 'C:\Users\dell\Documents\Doktora\Tez.Modeller.Defense\Two.Sector\IncludeFiles\CD_Lignite1.inc'
$include 'C:\Users\dell\Documents\Doktora\Tez.Modeller.Defense\Two.Sector\IncludeFiles\CD_Lignite2.inc'
$include 'C:\Users\dell\Documents\Doktora\Tez.Modeller.Defense\Two.Sector\IncludeFiles\CD_Lignite3.inc'
$include 'C:\Users\dell\Documents\Doktora\Tez.Modeller.Defense\Two.Sector\IncludeFiles\CD_Pet.inc'
$include 'C:\Users\dell\Documents\Doktora\Tez.Modeller.Defense\Two.Sector\IncludeFiles\CD_Wood.inc'

$include 'C:\Users\dell\Documents\Doktora\Tez.Modeller.Defense\Two.Sector\IncludeFiles\CE_Coal.inc'
$include 'C:\Users\dell\Documents\Doktora\Tez.Modeller.Defense\Two.Sector\IncludeFiles\CE_HydroDam.inc'
$include 'C:\Users\dell\Documents\Doktora\Tez.Modeller.Defense\Two.Sector\IncludeFiles\CE_HydroRiver.inc'
$include 'C:\Users\dell\Documents\Doktora\Tez.Modeller.Defense\Two.Sector\IncludeFiles\CE_Lignite.inc'
$include 'C:\Users\dell\Documents\Doktora\Tez.Modeller.Defense\Two.Sector\IncludeFiles\CE_Naturalgas.inc'
$include 'C:\Users\dell\Documents\Doktora\Tez.Modeller.Defense\Two.Sector\IncludeFiles\CE_Nuclear.inc'
$include 'C:\Users\dell\Documents\Doktora\Tez.Modeller.Defense\Two.Sector\IncludeFiles\CE_Pet.inc'
$include 'C:\Users\dell\Documents\Doktora\Tez.Modeller.Defense\Two.Sector\IncludeFiles\CE_Wind.inc'
$include 'C:\Users\dell\Documents\Doktora\Tez.Modeller.Defense\Two.Sector\IncludeFiles\CE_Geothermal.inc'
$include 'C:\Users\dell\Documents\Doktora\Tez.Modeller.Defense\Two.Sector\IncludeFiles\CE_Solar.inc'
$include 'C:\Users\dell\Documents\Doktora\Tez.Modeller.Defense\Two.Sector\IncludeFiles\CE_Nuclear.inc'

$include 'C:\Users\dell\Documents\Doktora\Tez.Modeller.Defense\Two.Sector\IncludeFiles10\CI_Coal.inc'
$include
'C:\Users\dell\Documents\Doktora\Tez.Modeller.Defense\Two.Sector\IncludeFiles10\CI_HydroDam.inc'
$include
'C:\Users\dell\Documents\Doktora\Tez.Modeller.Defense\Two.Sector\IncludeFiles10\CI_HydroRiver.inc'
$include 'C:\Users\dell\Documents\Doktora\Tez.Modeller.Defense\Two.Sector\IncludeFiles10\CI_Lignite.inc'
$include 'C:\Users\dell\Documents\Doktora\Tez.Modeller.Defense\Two.Sector\IncludeFiles10\CI_Naturalgas.inc'
$include 'C:\Users\dell\Documents\Doktora\Tez.Modeller.Defense\Two.Sector\IncludeFiles10\CI_Nuclear.inc'
$include 'C:\Users\dell\Documents\Doktora\Tez.Modeller.Defense\Two.Sector\IncludeFiles10\CI_Pet.inc'
$include 'C:\Users\dell\Documents\Doktora\Tez.Modeller.Defense\Two.Sector\IncludeFiles10\CI_Wind.inc'
$include
'C:\Users\dell\Documents\Doktora\Tez.Modeller.Defense\Two.Sector\IncludeFiles10\CI_Geothermal.inc'
$include 'C:\Users\dell\Documents\Doktora\Tez.Modeller.Defense\Two.Sector\IncludeFiles10\CI_Solar.inc'
$include 'C:\Users\dell\Documents\Doktora\Tez.Modeller.Defense\Two.Sector\IncludeFiles10\CI_Nuclear.inc'

$include 'C:\Users\dell\Documents\Doktora\Tez.Modeller.Defense\Two.Sector\IncludeFiles\CF_Coal.inc'
$include 'C:\Users\dell\Documents\Doktora\Tez.Modeller.Defense\Two.Sector\IncludeFiles\CF_NaturalGas.inc'
$include 'C:\Users\dell\Documents\Doktora\Tez.Modeller.Defense\Two.Sector\IncludeFiles\CF_Pet.inc'
$include 'C:\Users\dell\Documents\Doktora\Tez.Modeller.Defense\Two.Sector\IncludeFiles\CF_Nuclear.inc'

cf("NaturalGas",t)=dGas*cf("NaturalGas",t);

$include 'C:\Users\dell\Documents\Doktora\Tez.Modeller.Defense\Two.Sector\IncludeFiles\EmissionFactors.inc'
$include 'C:\Users\dell\Documents\Doktora\Tez.Modeller.Defense\Two.Sector\IncludeFiles\DepF.inc'

*============================================================================
*Estimation of conversion parameters
*============================================================================
conv("Lignite1")                    = (TotLign1_0-LIGN1_0)/ELIGN1_0;
conv("Lignite2")                    = (TotLign2_0-LIGN2_0)/ELIGN2_0;
conv("Lignite3")                    = (TotLign3_0-LIGN3_0)/ELIGN3_0;
conv("Coal")                        = (TotCoalF0-COALF0("Whole"))/ECOAL0;
conv("PetroleumProducts")           = (TotPetF0-PETF0("Whole"))/EPET0;
conv("NaturalGas")                  = (TotNG0-N0("Whole"))/ENGAS0;
```

```
*==============================================================================
*Calculation of base year Electricity Consumption, Energy Costs, Total Investment
*Imports, GDP, VA, Gross Output and Consumption
*==============================================================================

ELIGN0          = ELIGN1_0+ELIGN2_0+ELIGN3_0;

EREN0           = EGEO0+EWND0+ESOL0;

E0("Whole")     = EHYDR0+ELIGN0+EPET0+ECOAL0+ENGAS0+EREN0+ENUC0;

ECD0("Whole")  = cd("Coal","2003")*COALD0("Whole")+
                 cd("PetroleumProducts","2003")*PETD0("Whole")+
                 cd("Lignite1","2003")*TotLign1_0+
                 cd("Lignite2","2003")*TotLign2_0+
                 cd("Lignite3","2003")*TotLign3_0+
                 cd("Wood","2003")*WOOD0("Whole")+
                 ce("HydroDam","2003")*EHYDRODAM0+
                 ce("HydroRIVER","2003")*EHYDRORIVER0+
                 ce("Lignite","2003")*ELIGN0+
                 ce("PetroleumProducts","2003")*EPET0+
                 ce("Coal","2003")*ECOAL0+
                 ce("NaturalGas","2003")*ENGAS0+
                 ce("Wind","2003")*EWND0+
                 ce("Geothermal","2003")*EGEO0+
                 ce("Solar","2003")*ESOL0+
                 ce("Nuclear","2003")*ENUC0+
                 ci("Lignite","2003")*ELIGN1_0+
                 ci("Lignite","2003")*ELIGN2_0+
                 ci("Lignite","2003")*ELIGN3_0+
                 ci("HydroDAM","2003")*EHYDRODAM0+
                 ci("HydroRIVER","2003")*EHYDRORIVER0+
                 ci("PetroleumProducts","2003")*EPET0+
                 ci("NaturalGas","2003")*ENGAS0+
                 ci("Coal","2003")*ECOAL0+
                 ci("Wind","2003")*EWND0+
                 ci("Geothermal","2003")*EGEO0+
                 ci("Solar","2003")*ESOL0+
                 ci("Nuclear","2003")*ENUC0;
```

```
pelec0          = td*(
                cd("Lignite1","2003")*conv("Lignite1")*ELIGN1_0+
                cd("Lignite2","2003")*conv("Lignite2")*ELIGN2_0+
                cd("Lignite3","2003")*conv("Lignite3")*ELIGN3_0+
                cf("PetroleumProducts","2003")*conv("PetroleumProducts")*EPET0+
                cf("Coal","2003")*conv("Coal")*ECOAL0+
                cf("NaturalGas","2003")*conv("NaturalGas")*ENGAS0+
                cf("Nuclear","2003")*ENUC0+
                ce("HydroDAM","2003")*EHYDRODAM0+
                ce("HydroRIVER","2003")*EHYDRORIVER0+
                ce("Lignite","2003")*ELIGN0+
                ce("PetroleumProducts","2003")*EPET0+
                ce("Coal","2003")*ECOAL0+
                ce("NaturalGas","2003")*ENGAS0+
                ce("Wind","2003")*EWND0+
                ce("Geothermal","2003")*EGEO0+
                ce("Solar","2003")*ESOL0+
                ce("Nuclear","2003")*ENUC0+
                ci("Lignite","2003")*ELIGN1_0+
                ci("Lignite","2003")*ELIGN2_0+
                ci("Lignite","2003")*ELIGN3_0+
                ci("HydroDAM","2003")*EHYDRODAM0+
                ci("HydroRIVER","2003")*EHYDRORIVER0+
                ci("PetroleumProducts","2003")*EPET0+
                ci("NaturalGas","2003")*ENGAS0+
                ci("Coal","2003")*ECOAL0+
                ci("Wind","2003")*EWND0+
                ci("Geothermal","2003")*EGEO0+
                ci("Solar","2003")*ESOL0+
                ci("Nuclear","2003")*ENUC0
                )
                / E0("Whole");

plign0          = (
                cd("Lignite1","2003")*TotLign1_0+
                cd("Lignite2","2003")*TotLign2_0+
                cd("Lignite3","2003")*TotLign3_0
                )
                / TotLign0;

ForElecCoef0    = td*(
                cf("PetroleumProducts","2003")*conv("PetroleumProducts")*EPET0+
                cf("Coal","2003")*conv("Coal")*ECOAL0+
                cf("NaturalGas","2003")*conv("NaturalGas")*ENGAS0+
                cf("Nuclear","2003")*ENUC0+
                0.75*ci("Lignite","2003")*ELIGN1_0+
                0.75*ci("Lignite","2003")*ELIGN2_0+
                0.75*ci("Lignite","2003")*ELIGN3_0+
                0.50*ci("HydroDAM","2003")*EHYDRODAM0+
                0.75*ci("HydroRIVER","2003")*EHYDRORIVER0+
                0.75*ci("PetroleumProducts","2003")*EPET0+
                0.75*ci("NaturalGas","2003")*ENGAS0+
                0.75*ci("Coal","2003")*ECOAL0+
                0.75*ci("Wind","2003")*EWND0+
                0.75*ci("Geothermal","2003")*EGEO0+
                0.75*ci("Solar","2003")*ESOL0+
                ci("Nuclear","2003")*ENUC0
                )/(pelec0*E0("Whole"));
```

```
DomElecCoef0   = (1-ForElecCoef0);

ECD0(i)        = DomElecCoef0*pelec0*E0(i)+
                 cd("PetroleumProducts","2003")*PETD0(i)+
                 plign0*Lign0(i)+
                 cd("Coal","2003")*COALD0(i)+
                 cd("Wood","2003")*Wood0(i);

ECD0("Whole")  = sum(i,ECD0(i));

ECF0(i)        = ForElecCoef0*pelec0*E0(i)+
                 cf("NaturalGas","2003")*N0(i)+
                 cf("PetroleumProducts","2003")*PETF0(i)+
                 cf("Coal","2003")*CoalF0(i);

ECF0("Whole")
               = (cf("Coal","2003")*TotCoalF0+cf("PetroleumProducts","2003")*TotPetF0 +
                 cf("NaturalGas","2003")*TotNG0+
                 0.75*ci("Lignite","2003")*ELIGN1_0+
                 0.75*ci("Lignite","2003")*ELIGN2_0+
                 0.75*ci("Lignite","2003")*ELIGN3_0+
                 0.50*ci("HydroDAM","2003")*EHYDRODAM0+
                 0.75*ci("HydroRIVER","2003")*EHYDRORIVER0+
                 0.75*ci("PetroleumProducts","2003")*EPET0+
                 0.75*ci("NaturalGas","2003")*ENGAS0+
                 0.75*ci("Coal","2003")*ECOAL0+
                 0.75*ci("Wind","2003")*EWND0+
                 0.75*ci("Geothermal","2003")*EGEO0+
                 0.75*ci("Solar","2003")*ESOL0+
                 ci("Nuclear","2003")*ENUC0
                 );

EC0(i0)        = ECD0(i0)+er0*ECF0(i0);

EC0("Whole")   = sum(i,EC0(i));

M0(i)          = sum(j,InvestF0(i,j))+sum(j,InterF0(i,j))+CGF0(i);
M0("Whole")    = sum(i,M0(i))+ECF0("Whole");
X0("Whole")    = sum(i,X0(i))+NRH0;
VA0(i)         = sum(j,Inter0(i,j))+(C0(i)+sum(j,Invest0(i,j))+X0(i))-M0(i)-ECD0(i)-er0*ECF0(i)-
                 sum(j,Inter0(j,i));
Y0(i)          = sum(j,Inter0(j,i))+VA0(i)+ECD0(i)+er0*ECF0(i);
GDP0           = sum(i,VA0(i))+NRH0;

XtoVA(i)       = X0(i)/VA0(i);
MtoVA(i)       = M0(i)/VA0(i);
NRHtoX         = NRH0/sum(i,X0(i));

fc(t)          = 0.060;
*fc(t+8)       = 0.070;

fc("2004")     = 0.034;
fc("2005")     = 0.040;

*==================================================================
DISPLAY Y0, GDP0, VA0, ECD0, ECF0, EC0, E0, P0, S0, N0, Inter0, CGD0, CGF0, X0, M0, C0,
E0, P0, N0, NRHtoX, S0, DomElecCoef0, ForElecCoef0;
```

```
*==========================================================================
PARAMETERS
*==========================================================================*
Parameters of the CES Function
*==========================================================================

a1(i)           Scale parameter for Aggregate 1 in sector i
a2(i)           Scale parameter for Aggregate 2 in sector i
sl(i)           Share parameter for Labor in sector i
sk(i)           Share parameter for Capital in sector i
se(i)           Share parameter for Electricity in sector i
sp(i)           Share parameter for Petroleum Products in sector i
sng(i)          Share parameter for Natural Gas in sector i
ss(i)           Share parameter for Solid Fuels in sector i
rho
sigma(i)        Elasticity of substitution in sector i
theta(i)        Share parameter of consumption of sector i goods
ROCratio(i)     Return on capital ratio for sector i
scd(i)          Share parameter for domestic consumption goods in sector i
scg(i)          Share parameter for foreign consumption goods in sector i
alpha(i)        Distribution parameter for Capital-Labor aggregate in sector i
beta(i)         Distribution parameter for Intermediates in sector i
mu(i)           Scale parameter for capital formation of sector i
;

PARAMETERS
sintf(i,j)              Share parameter for intermediates i used by sector j-foreign
sintd(i,j)              Share parameter for intermediates i used by sector j-domestic
AlphinvD(i,j)           Share parameters for investment made by sector j on good i-domestic
AlphinvF(i,j)           Share parameters for investment made by sector j on good i-imported
gamma(i,t)              Scale parameter-sector i
GrowthGamma(i,t)        Growth parameter for gamma-sector i

IntToY0(i)              Intermediates to gross output ratio in sector i
sinvd(i,j)              Share parameters for investment made by sector j on good i-domestic
sinvf(i,j)              Share parameters for investment made by sector j on good i-imported
;

AlphinvD(j,i)     = InvestD0(j,i)/sum(jj,Invest0(jj,i));
AlphinvF(j,i)     = InvestF0(j,i)/sum(jj,Invest0(jj,i));

sinvd(i,j)        = InvestD0(i,j)/sum((ii,jj),Invest0(ii,jj));
sinvf(i,j)        = InvestF0(i,j)/sum((ii,jj),Invest0(ii,jj));

mu(i)             = sum(j,Invest0(j,i))/ ( prod(j, (
                  (InvestD0(j,i)**alphinvD(j,i))*(InvestF0(j,i)**alphinvF(j,i)) ) ) );

*==========================================================================
*Assignment of Base Year Labor Values
*==========================================================================
L0("Agriculture","2003")          =  21542.770;
L0("IndHighEn","2003")            =    6485.144;
L0("IndOth","2003")               =  20724.859;
L0("Services","2003")             =  84199.664;
L0("Transport","2003")            =    8850.539;

L0("Whole","2003")                = sum(i,L0(i,"2003"));
Loop(i,L0(i,"2003")               = L0(i,"2003")/L0("Whole","2003"));
L0("Whole","2003")                = sum(i,L0(i,"2003"));
```

```
*==========================================================================
*Initial estimates for some of CES function parameters, exchange rate and Labor
*==========================================================================

sl("Agriculture")           = 0.45-0.00;
sl("IndHighEn")             = 0.35-0.00;
sl("IndOth")                = 0.35-0.00;
sl("Services")              = 0.35-0.00;
sl("Transport")             = 0.20-0.00;

sk("Agriculture")           = 1-sl("Agriculture");
sk("IndHighEn")             = 1-sl("IndHighEn");
sk("IndOth")                = 1-sl("IndOth");
sk("Services")              = 1-sl("Services");
sk("Transport")             = 1-sl("Transport");

sigma("Agriculture")        = 0.400;
sigma("IndHighEn")          = 0.350;
sigma("IndOth")             = 0.350;
sigma("Services")           = 0.300;
sigma("Transport")          = 0.350;

rho(i)                      = (sigma(i)-1)/sigma(i);
er(t)                       =1;
scd(i)                      = CGD0(i)/C0(i);
scg(i)                      = 1-scd(i);
sintf(j,i)                  = InterF0(j,i)/Y0(i);
sintd(j,i)                  = InterD0(j,i)/Y0(i);
IntToY0(i)                  = sum(jj,Inter0(jj,i))/Y0(i);
theta(i)                    = C0(i)/C0("Whole");

*==========================================================================
DISPLAY conv,L0,IntToY0, sintd, sintf;
*==========================================================================
*==========================================================================
*Estimation of CES Function Parameters
*==========================================================================

se(i)              = pelec0*E0(i)/EC0(i);
sp(i)              =
                   (cd("PetroleumProducts","2003")*PETD0(i)+cf("PetroleumProducts","2003")*PET
                   F0(i))/EC0(i);
sng(i)             = cf("NaturalGas","2003")*N0(i)/EC0(i);
ss(i)              = (
                   plign0*Lign0(i)+
                   cd("Coal","2003")*COALD0(i)+
                   cf("Coal","2003")*CoalF0(i)+
                   cd("Wood","2003")*Wood0(i)
                   )
                   /
                   EC0(i);

ppet0(i)           = (
                   cd("PetroleumProducts","2003")*PETD0(i)+
                   cf("PetroleumProducts","2003")*PETF0(i)
                   )
                   /
                   (PETD0(i)+PETF0(i));
```

```
psol0(i)$(S0(i) ne 0)        = (
                             plign0*Lign0(i)+
                             cd("Coal","2003")*COALD0(i)+
                             cf("Coal","2003")*CoalF0(i)+
                             cd("Wood","2003")*Wood0(i)
                             )
                             /
                             (Lign0(i)+CoalD0(i)+CoalF0(i)+Wood0(i));


penergy0(i)                  = (
                             pelec0*E0(i)+
                             cf("NaturalGas","2003")*N0(i)+
                             psol0(i)*S0(i)+
                             ppet0(i)*P0(i)
                             )
                             /
                             (E0(i)+N0(i)+S0(i)+P0(i));

*======================================================================

ROCratio("Agriculture")  = 0.400;
ROCratio("IndHighEn")    = 0.200;
ROCratio("IndOth")       = 0.150;
ROCratio("Services")     = 0.200;
ROCratio("Transport")    = 0.100;

a1(i)                    = ROCratio(i)
                         /
                          (
                         sk(i)*
                          (VA0(i)+ECD0(i)+ECF0(i))**(1-rho(i))*
                         K0(i)**(sk(i)*rho(i)-1)*L0(i,"2003")**(sl(i)*rho(i)
                         )
                         );

a2(i)                    = (
                          (VA0(i)+ECD0(i)+ECF0(i))**rho(i) -
                         a1(i)*K0(i)**(sk(i)*rho(i))*L0(i,"2003")**(sl(i)*rho(i))
                         )
                         /
                          ( E0(i)**( se(i)*rho(i) ) * P0(i)**( sp(i)*rho(i) ) * N0(i)**( sng(i)*rho(i) )
                         * S0(i)**(ss(i)*rho(i)) );

gamma(i,"2003")          =  (a1(i)+a2(i))**(1/rho(i));
alpha(i)                 =  a1(i)/(a1(i)+a2(i));


*======================================================================
*Incorporating Technical Progress
*======================================================================
Loop(t,GrowthGamma("IndHighEn",t+1)    = (1+0.0200*(0.90** sqrt(ord(t)) )) );
Loop(t,GrowthGamma("IndOth",t+1)       = (1+0.0200*(0.90** sqrt(ord(t)) )) );
Loop(t,GrowthGamma("Agriculture",t+1)  = (1+0.0050*(1.00** sqrt(ord(t)) )) );
Loop(t,GrowthGamma("Services",t+1)     = (1+0.0100*(1.10** sqrt(ord(t)) )) );
Loop(t,GrowthGamma("Transport",t+1)    = (1+0.0100*(1.10** sqrt(ord(t)) )) );
Loop((i,t),gamma(i,t+1)                = GrowthGamma(i,t+1)*gamma(i,t));
*======================================================================
DISPLAY GrowthGamma, se, sp, sng, ss, a1, a2, gamma, alpha, scd, scg, psol0, ppet0, penergy0;
```

*===
VARIABLES
*===

K(i,t)	Capital Stock-sector i, year t
KN(i,t)	New Capital Stock-sector i, year t
L(i0,tdum)	Labor-sector i, year t
LN(i0,tdum)	New labor-sector i, year t
Inter(i,j,t)	Good i demanded by sector j in year t as intermediates
InterD(i,j,t)	Good i demanded by sector j in year t as intermediates-domestic
InterF(i,j,t)	Good i demanded by sector j in year t as intermediates-imported
IntToY(i,t)	Intermediates to gross output ratio-sector i, year t
Y(i,t)	Gross Output-sector i, year t
YN(i,t)	New Gross Output-sector i, year t
VA(i,t)	Value-added-sector i, year t
E(i0,t)	Electric energy demand-sector i, year t
EN(i,t)	New electric energy demand-sector i, year t
P(i0,t)	Petroleum Products demand-sector i, year t
PN(i,t)	New Petroleum Products demand-sector i, year t
N(i0,t)	Natural Gas demand-sector i, year t
NN(i,t)	New Natural Gas demand-sector i, year t
S(i0,t)	Solid Fuels demand-sector i, year t
SN(i,t)	New Solid Fuels demand-sector i, year t
COALD(i0,t)	Domestic coal consumption for non-electric use-sector i, year t
COALF(i0,t)	Foreign coal consumption for non-electric use-sector i, year t
PETD(i0,t)	Domestic pet. products consumption for non-electric use-sector i, year t
PETF(i0,t)	Imported pet. products consumption for non-electric use-sector i, year t
LIGN(i0,t)	Lignite consumption for non-electric use-sector i, year t
LIGN1(t)	Lignite 1 consumption for non-electric use-sector i, year t
LIGN2(t)	Lignite 2 consumption for non-electric use-sector i, year t
LIGN3(t)	Lignite 3 consumption for non-electric use-sector i, year t
WOOD(i0,t)	Wood consumption for non-electric use-sector i, year t
EPET(t)	Electricity Produced By Petroleum Products Power Plants in year t
ECOAL(t)	Electricity Produced By Hard-coal Power Plants in year t
ENGAS(t)	Electricity Produced By Natural gas Power Plants in year t
EREN(t)	Electricity Produced By Renewables in year t
EWND(t)	Electricity Produced By Wind in year t
EGEO(t)	Electricity Produced By Geothermal in year t
ESOL(t)	Electricity Produced By Solar in year t
ENUC(t)	Electricity Produced By Nuclear Power Plants in year t
EHYDR(t)	Electricity Produced By Hydro Power Plant in year t
EHYDRODAM(t)	Electricity Produced By HydroDAM Power Plant in year t
EHYDRORIVER(t)	Electricity Produced By HydroRIVER Power Plant in year t
ELIGN(t)	Electricity Produced By Lignite Power Plant in year t
ELIGN1(t)	Electricity Produced By Lignite 1 Power Plant in year t
ELIGN2(t)	Electricity Produced By Lignite 2 Power Plant in year
ELIGN3(t)	Electricity Produced By Lignite 3 Power Plant in year t
Inc(ee,t)	Incremental capacity of power plant ee in year t
TotLign(t)	Total lignite consumption -for electricity and non-electric use- in year t
TotLign1(t)	Total lignite 1 consumption -for electricity and non-electric use- in year t
TotLign2(t)	Total lignite 2 consumption -for electricity and non-electric use- in year t
TotLign3(t)	Total lignite 3 consumption -for electricity and non-electric use- in year t
TotPetF(t)	Total Foreign Petroleum Products consumption -for electricity and non-electric use- in year t
TotCoalF(t)	Total Foreign Coal consumption -for electricity and non-electric use- in year t
TotNG(t)	Total natural gas consumption -for electricity and non-electric use- in year t
ECD(i0,t)	Energy Costs- domestic, sector i, year t
ECF(i0,t)	Energy Costs- foreign, sector i, year t

```
Invest(i,j,t)          Investment made by sector j on good i in year t
InvestD(i,j,t)         Investment made by sector j on good i in year t- domestic
InvestF(i,j,t)         Investment made by sector j on good i in year t- foreign
Inv(t)                 Total investment
InvD(t)                Total investment on domestic goods
InvF(t)                Total investment on foreign goods
X(i0,t)                Exports- sector i, year t
M(i0,t)                Imports- sector i, year t
F(t)                   Foreign capital inflows in year t
NRH(t)                 Fin. Cons. Exp. of Non-Res HHs on the Economic Territory-year t
GDP(t)                 Gross Domestic Product in year t
C(i,t)                 Consumption- sector i, year t
CGF(i,t)               Consumption- sector i, year t-foreign
CGD(i,t)               Consumption- sector i, year t-domestic
Obj                    Sum of discounted consumption
GHG(g,i0,t)            GHG of type g emission- sector i, year t
GHGElec(t)             GHG emission due to electricity generation in year t
pelec(t)               Average electricity price in year t
plign(t)               Average lignite price in year t
DomElecCoef(t)         Share of domestic costs in total cost of generating electricity
ForElecCoef(t)         Share of foreign costs in total cost of generating electricity
;

*============================================================================
*Setting initial values, upper and lower bounds
*============================================================================
$include 'C:\Users\dell\Documents\Doktora\Tez.Modeller.Defense\Two.Sector\IncludeFiles\InitialLevel.inc'
$include 'C:\Users\dell\Documents\Doktora\Tez.Modeller.Defense\Two.Sector\IncludeFiles\InitialLower.inc '
$include 'C:\Users\dell\Documents\Doktora\Tez.Modeller.Defense\Two.Sector\IncludeFiles\InitialUpper.inc'
$include
'C:\Users\dell\Documents\Doktora\Tez.Modeller.Defense\Two.Sector\IncludeFiles\LaborGrowthWholeV3.inc'
*============================================================================
Display L.l;
*============================================================================

*============================================================================
EQUATIONS
*============================================================================

NCapPro (i,t)          Capital accumulation- C-D function of recent investments, sector i, year t
NCapSum (i,t)          Capital accumulation- average of recent investments, sector i, year t
TotInvD(t)             Total Investment-aggregated, domestic
TotInvF(t)             Total Investment-aggregated, foreign
TotInv(i,t)            Total Investment-aggregated
TotInvest(i,j,t)       Inter-sectoral flow of investments-sum of domestic and foreign
                       components, year t
InvestDConL(i,j,t)     Inter-sectoral flow of investments-lower bound, year t, domestic
InvestDConU(i,j,t)     Inter-sectoral flow of investments-upper bound, year t, domestic
InvestFConL(i,j,t)     Inter-sectoral flow of investments-lower bound, year t, foreign
InvestFConU(i,j,t)     Inter-sectoral flow of investments-upper bound, year t, foreign
InvLast                Investment of last year
TotSecC(i,t)           Sectoral consumption-sum of domestic and foreign components, year t
NGrOut(i,t)            New Gross Output in year t
InterToYcon(i,t)       IntToY variable- sector i, year t
InterYDL(j,i,t)        Inter-sectoral flow of intermediates-lower bound, year t, domestic
InterYFL(j,i,t)        Inter-sectoral flow of intermediates-lower bound, year t, foreign
InterYDU(j,i,t)        Inter-sectoral flow of intermediates-upper bound, year t, domestic
InterYFU(j,i,t)        Inter-sectoral flow of intermediates-upper bound, year t, foreign
```

TotInter(i,j,t)	Inter-sectoral flow of intermediates-sum of domestic and foreign components, year t
GrOut(i,t)	Change of factor stocks -gross output- sector i, year t
Captl(i,t)	Change of factor stocks -capital- sector i, year t
Labor(i,t)	Change of factor stocks -labor- sector i, year t
LaborWhole(t)	Disaggregation of total labor
Elc(i,t)	Change of factor stocks -electricity- sector i, year t
Pet(i,t)	Change of factor stocks –pet. products- sector i, year t
NG(i,t)	Change of factor stocks –natural gas- sector i, year t
Sol(i,t)	Change of factor stocks –solid fuels- sector i, year t
Imports(i,t)	Imports- sector i, year t
TotImports(t)	Total imports in year t
XSecConstL(i,t)	Sectoral exports-Lower bound, sector i
MSecConstL(i,t)	Sectoral imports-Upper bound, sector i
ToteXports(t)	Total Exports-sum of sectoral exports and NRH
ForExc(t)	Foreign exchange constraint in year t
Fconst(t)	Constraint on foreign capital inflow
NRHconstL(t)	NRH-Lower bound, year t
NRHconstU(t)	NRH-Upper bound, year t
ElcGene(t)	Electricity generation in year t- sum of supplies
ElecSecTot(t)	Electricity generation in year t- sum of sectoral demands
SolProd(i0,t)	Solid Fuels demand for non-electric use- sector i, year t
CoalSecTotD(t)	Coal demand in year t-domestic, sum of sectoral demands
CoalSecTotF(t)	Coal demand in year t-foreign, sum of sectoral demands
PetSup(i0,t)	Pet. products demand for non-electric use- sum of domestic and foreign components, sector i, year t
PetSecTotD(t)	Pet. products demand in year t-domestic, sum of sectoral demands
PetSecTotF(t)	Pet. products demand in year t-foreign, sum of sectoral demands
PetSecTot(t)	Pet. products demand in year t- sum of sectoral demands
LignSup(t)	Total lignite supply - sum of regional supplies, year t
LignSecTot(t)	Total lignite demand - sum of sectoral demands, year t
WoodSecTot(t)	Total wood demand - sum of sectoral demands, year t
NGSecTot(t)	Total gas demand - sum of sectoral demands, year t
TotELign(t)	Electricity by lignite- sum of regional supplies, year t
TotLigCon(t)	Total-lignite supply- sum of regional supplies, year t
TotLig1Con(t)	Total-lignite 1 supply- sum of elec. and non-elec. cons., year t
TotLig2Con(t)	Total-lignite 2 supply- sum of elec. and non-elec. cons., year t
TotLig3Con(t)	Total-lignite 3 supply- sum of elec. and non-elec. cons., year t
TotPetFCon(t)	Total-pet. products supply- foreign, sum of elec. and non-elec. cons., year t
TotCoalFCon(t)	Total-coal supply- foreign, sum of elec. and non-elec. cons., year t
TotNGCon(t)	Total-gas supply- foreign, sum of elec. and non-elec. cons., year t
TotLig1ConU(t)	Total-Lignite 1 supply- upper bound, in year t
TotLig2ConU(t)	Total-Lignite 2 supply- upper bound, in year t
TotLig3ConU(t)	Total-Lignite 3 supply- upper bound, in year t
TotPetFConU(t)	Total-pet. products supply- foreign, upper bound, year t
TotCoalFConU(t)	Total-coal supply- foreign, upper bound, year t
TotNGConU(t)	Total-gas supply- foreign, upper bound, year t
TotSecCoalFConU(t)	Non-elec.-coal supply- foreign, upper bound, year t
TotCoalDU(t)	Non-elec.-coal supply- domestic, upper bound, year t
TotWoodU(t)	Total-wood supply- upper bound, year t
TotLIGNU(t)	Non-elec.-Lignite 1 supply- upper bound, in year t
CoalFConU(i,t)	Sectoral-coal demand- foreign, upper bound, year t
CoalDU(i,t)	Sectoral-coal demand- domestic, upper bound, year t
WOODU(i,t)	Sectoral-wood demand- upper bound, year t
LIGNU(i,t)	Sectoral-lignite demand- upper bound, year t
PETDU(i,t)	Sectoral-pet. products demand- domestic, upper bound, year t
PETFU(i,t)	Sectoral-pet. products demand- foreign, upper bound, year t
TotLig1ConL(t)	Total-Lignite 1 supply- lower bound, in year t

TotLig2ConL(t)	Total-Lignite 2 supply- lower bound, in year t
TotLig3ConL(t)	Total-Lignite 3 supply- lower bound, in year t
TotPetDConL(t)	Total-pet. products supply- domestic, lower bound, year t
TotPetFConL(t)	Total-pet. products supply- foreign, lower bound, year t
TotCoalFConL(t)	Total-coal supply- foreign, lower bound, year t
TotNGConL(t)	Total-gas supply- foreign, lower bound, year t
TotSecCoalFConL(t)	Non-elec.-coal supply- foreign, lower bound, year t
TotCoalDL(t)	Non-elec.-coal supply- domestic, lower bound, year t
TotWoodL(t)	Total-wood supply- lower bound, year t
TotLIGNL(t)	Non-elec.-Lignite 1 supply- lower bound, in year t
CoalFConL(i,t)	Sectoral-coal demand- foreign, lower bound, year t
CoalDL(i,t)	Sectoral-coal demand- domestic, lower bound, year t
WOODL(i,t)	Sectoral-wood demand- lower bound, year t
LIGNL(i,t)	Sectoral-lignite demand- lower bound, year t
PETDL(i,t)	Sectoral-pet. products demand- domestic, lower bound, year t
PETFL(i,t)	Sectoral-pet. products demand- foreign, lower bound, year t
GroTotPetDCon	Cumulative total- Petroleum supply- domestic
GroTotLig1Con	Cumulative total - Lignite 1- domestic
GroTotLig2Con	Cumulative total - Lignite 2- domestic
GroTotLig3Con	Cumulative total - Lignite 3- domestic
GroTotCoalDCon	Cumulative total - Coal- domestic
HydroSup(t)	Hydroelectricity- sum of dam and run of river
HydroDAMCon(t)	Hydroelectricity –dam – potential, year t
HydroRIVERCon(t)	Hydroelectricity –run of river – potential, year t
GeothermalCon(t)	Geothermal- potential, year t
WindCon(t)	Wind- potential, year t
SolarCon(t)	Solar- potential, year t
IncEleLig1L(t)	Incremental capacity- Lignite 1 Plants- lower bound, year t
IncEleLig2L(t)	Incremental capacity- Lignite 2 Plants- lower bound, year t
IncEleLig3L(t)	Incremental capacity- Lignite 3 Plants- lower bound, year t
IncEleHydDAML(t)	Incremental capacity- Hydro-dam - lower bound, year t
IncEleHydRIVERL(t)	Incremental capacity- Hydro-river- lower bound, year t
IncElePetL(t)	Incremental capacity- Pet. Products Plants- lower bound, year t
IncEleNGasL(t)	Incremental capacity- Natural gas Plants- lower bound, year t
IncEleCoalL(t)	Incremental capacity- Coal Plants- lower bound, year t
IncEleWndL(t)	Incremental capacity- Wind Plants- lower bound, year t
IncEleGeoL(t)	Incremental capacity- Geothermal Plants- lower bound, year t
IncEleSolL(t)	Incremental capacity- Solar Plants- lower bound, year t
IncEleNucL(t)	Incremental capacity- Nuclear Plants- lower bound, year t
IncEleLig1U(t)	Incremental capacity- Lignite 1 Plants- upper bound, year t
IncEleLig2U(t)	Incremental capacity- Lignite 2 Plants- upper bound, year t
IncEleLig3U(t)	Incremental capacity- Lignite 3 Plants- upper bound, year t
IncEleHydDAMU(t)	Incremental capacity- Hydro-dam - upper bound, year t
IncEleHydRIVERU(t)	Incremental capacity- Hydro-river- upper bound, year t
IncElePetU(t)	Incremental capacity- Pet. Products Plants- upper bound, year t
IncEleNGasU(t)	Incremental capacity- Natural gas Plants- upper bound, year t
IncEleCoalU(t)	Incremental capacity- Coal Plants- upper bound, year t
IncEleWndU(t)	Incremental capacity- Wind Plants- upper bound, year t
IncEleGeoU(t)	Incremental capacity- Geothermal Plants- upper bound, year t
IncEleSolU(t)	Incremental capacity- Solar Plants- upper bound, year t
IncEleNucU(t)	Incremental capacity- Nuclear Plants- upper bound, year t
CapEleLign1(t)	Continuity equations- Lignite 1 Plants- year t
CapEleLign2(t)	Continuity equations- Lignite 2 Plants- year t

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CapEleLign3(t)          Continuity equations- Lignite 3 Plants- year t
CapEleHydDAM(t)         Continuity equations- Hydro-dam - year t
CapEleHydRIVER(t)       Continuity equations- Hydro-river - year t
CapElePet(t)            Continuity equations- Pet. Products Plants- year t
CapEleNGas(t)           Continuity equations- Natural Gas Plants- year t
CapEleCoal(t)           Continuity equations- Coal Plants- year t
CapEleWnd(t)            Continuity equations- Wind Plants- year t
CapEleGeo(t)            Continuity equations- Geothermal Plants- year t
CapEleSol(t)            Continuity equations- Solar Plants- year t
CapEleNuc(t)            Continuity equations- Nuclear Plants- year t

GrossOutputRow(i,t)     Expenditures equals to revenues- sector i, year t
GrossOutputCol(i,t)     Gross output by expenditures - sector i, year t
GDPconst(t)             GDP equation

CO2Emission(i,t)        CO2 emissions- sector i, year t
TotalCO2Emission(t)     Total CO2 emissions in year t
CH4Emission(i,t)        CH4 emissions- sector i, year t
TotalCH4Emission(t)     Total CH4 emissions in year t
N2OEmission(i,t)        N2O emissions- sector i, year t
TotalN2OEmission(t)     Total N2O emissions in year t
TotalGHG(i,t)           Total- CO2 equivalent GHG emissions- sector i, year t
GHGElectricity(t)       Total emissions due to Electricity Generation in year t
GrandTotalGHG(t)        Total CO2 equivalent GHG emissions in year t

ElectricityPrice(t)     Average cost of generating electricity
LignitePrice(t)         Average cost of lignite
CoefficientForElec(t)   Domestic share of total cost of generating electricity
CoefficientDomElec(t)   Foreign share of total cost of generating electricity
SectoralEnergyCostD(i,t)        Energy Cost- domestic, secor i, year t
SectoralEnergyCostF(i,t)        Energy Cost- foreign, secor i, year t
Objective               Sum of discounted consumption
;

*=======================================================================

NCapProL(i,t+1)..       KN(i,t+1) =g= mu(i)* prod(j, sum(tt$( (ord(tt)<=ord(t)+1) and
                        (ord(tt)>=ord(t)-0) ),(1/2)*InvestD(j,i,tt))**alphinvD(j,i)*sum(tt$(
                        (ord(tt)<=ord(t)+1) and (ord(tt)>=ord(t)-0)
                        ),(1/2)*InvestF(j,i,tt))**alphinvF(j,i) );

 NCapSumL(i,t+1)..      KN(i,t+1) =g= sum(j,sum(tt$( (ord(tt)<=ord(t)+1) and (ord(tt)>=ord(t)-0) ),
                        (1/2)*InvestD(j,i,tt)+(1/2)*InvestF(j,i,tt)));

 NCapProU(i,t+1)..      KN(i,t+1) =l= mu(i)* prod(j, sum(tt$( (ord(tt)<=ord(t)+1) and
                        (ord(tt)>=ord(t)-0) ),(1/2)*InvestD(j,i,tt))**alphinvD(j,i)*sum(tt$(
                        (ord(tt)<=ord(t)+1) and (ord(tt)>=ord(t)-0)
                        ),(1/2)*InvestF(j,i,tt))**alphinvF(j,i) );

 NCapSumU(i,t+1)..      KN(i,t+1) =l= sum(j,sum(tt$( (ord(tt)<=ord(t)+1) and (ord(tt)>=ord(t)-0) ),
                        (1/2)*InvestD(j,i,tt)+(1/2)*InvestF(j,i,tt)));

 TotInvD(t+1)..         InvD(t+1) =e=  sum((i,j),InvestD(i,j,t+1));

 TotInvF(t+1)..         InvF(t+1) =e= sum((i,j),InvestF(i,j,t+1));

 TotInv(i,t+1)..        Inv(t+1) =e=  InvD(t+1)+er(t+1)*InvF(t+1);

 TotInvest(i,j,t)..     Invest(i,j,t+1) =e= InvestD(i,j,t+1)+er(t+1)*InvestF(i,j,t+1);
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```
TotInter(i,j,t)..            Inter(i,j,t+1) =e= InterD(i,j,t+1)+er(t+1)*InterF(i,j,t+1);

InvestDConL(i,j,t+1)..       InvestD(i,j,t+1) =g=  icL *sinvd(i,j)*Inv(t+1);

InvestDConU(i,j,t+1)..       InvestD(i,j,t+1) =l=  icU *sinvd(i,j)*Inv(t+1);

InvestFConL(i,j,t+1)..       InvestF(i,j,t+1) =g= icL *sinvf(i,j)*Inv(t+1);

InvestFConU(i,j,t+1)..       InvestF(i,j,t+1) =l= icU *sinvf(i,j)*Inv(t+1);

InvLast..                    sum((i,j), Invest(i,j,"2040")) =e= 0.075*sum(i, K(i,"2040"));

TotSecC(i,t+1)..             C(i,t+1) =e= CGD(i,t+1)+er(t+1)*CGF(i,t+1);

NGrOut(i,t+1)..              (1-IntToY(i,t+1))*YN(i,t+1) =e= gamma(i,t+1)* ( alpha(i)* (
                             (KN(i,t+1)**(sk(i)*rho(i))) * (LN(i,t+1)**(sl(i)*rho(i))) ) + (1-alpha(i))* (
                             (EN(i,t+1)**(se(i)*rho(i))) * (PN(i,t+1)**(sp(i)*rho(i))) *
                             (NN(i,t+1)**(sng(i)*rho(i))) * (SN(i,t+1)**(ss(i)*rho(i))) ) )**(1/rho(i));


InterToYcon(i,t+1)..         IntToY(i,t+1) =e= sum(j,Inter(j,i,t+1))/Y(i,t+1);

InterYDL(j,i,t+1)..          InterD(j,i,t+1) =g= (0.975-sqrt(ord(t))/100) * sintd(j,i)*Y(i,t+1);

InterYFL(j,i,t+1)..          InterF(j,i,t+1) =g= (0.975-sqrt(ord(t))/100) * sintf(j,i)*Y(i,t+1);

InterYDU(j,i,t+1)..          InterD(j,i,t+1) =l= (1.025+sqrt(ord(t))/100) * sintd(j,i)*Y(i,t+1);

InterYFU(j,i,t+1)..          InterF(j,i,t+1) =l= (1.025+sqrt(ord(t))/100) * sintf(j,i)*Y(i,t+1);

GrOut(i,t+1)..               Y(i,t+1) =e= YN(i,t+1)+lambda(i)*Y(i,t);

Captl(i,t+1)..               K(i,t+1) =e= KN(i,t+1)+klambda(i)*K(i,t);

Labor(i,t+1)..               L(i,t+1) =e= LN(i,t+1)+llambda(i)*L(i,t);

LaborWhole(t+1)..            L("Whole",t+1) =e= sum(i,L(i,t+1));

Elc(i,t+1)..                 E(i,t+1) =e= EN(i,t+1)+lambda(i)*E(i,t);

Pet(i,t+1)..                 P(i,t+1) =e= PN(i,t+1)+lambda(i)*P(i,t);

NG(i,t+1)..                  N(i,t+1) =e= NN(i,t+1)+lambda(i)*N(i,t);

Sol(i,t+1)..                 S(i,t+1) =e= SN(i,t+1)+lambda(i)*S(i,t);

Imports(i,t+1)..             M(i,t+1) =e= sum(j,InvestF(i,j,t+1))+sum(j,InterF(i,j,t+1))+CGF(i,t+1);


TotImports(t+1)..            M("Whole",t+1) =e= sum(i,M(i,t+1))+sum(i,ECF(i,t+1));

ForExc(t+1)..                M("Whole",t+1) =l= X("Whole",t+1)+F(t+1);

XSecConstL(i,t+1)..          X(i,t+1) =g= XMcL*XToVA(i)*VA(i,t+1);

MSecConstU(i,t+1)..          M(i,t+1) =l= XMcU*MToVA(i)*VA(i,t+1);

ToteXports(t+1)..            X("Whole",t+1) =e= sum(i,X(i,t+1))+NRH(t+1);
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Fconst(t+1)..          F(t+1) =l= fc(t+1)*GDP(t+1);

NRHconstL(t+1)..       NRH(t+1) =g= 0.275*(sum(i,X(i,t+1)));

NRHconstU(t+1)..       NRH(t+1) =l= 0.325*(sum(i,X(i,t+1)));

ElcGene(t+1)..         E("Whole",t+1) =e= EHYDRODAM(t+1)+
                       EHYDRORIVER(t+1)+ELIGN(t+1)+EPET(t+1)+ECOAL(t+1)+ENGAS(t
                       +1)+EWND(t+1)+EGEO(t+1)+ESOL(t+1)+ENUC(t+1);

ElecSecTot(t+1)..      E("Whole",t+1) =e= sum(i,E(i,t+1));

SolProd(i0,t+1)..      S(i0,t+1) =e=
                       COALD(i0,t+1)+COALF(i0,t+1)+LIGN(i0,t+1)+WOOD(i0,t+1);

CoalSecTotD(t+1)..     COALD("Whole",t+1) =e= sum(i,CoalD(i,t+1));

CoalSecTotF(t+1)..     COALF("Whole",t+1) =e= sum(i,CoalF(i,t+1));

PetSup(i0,t+1)..       P(i0,t+1) =e= PETD(i0,t+1)+PETF(i0,t+1);

PetSecTotD(t+1)..      PetD("Whole",t+1) =e= sum(i,PetD(i,t+1));

PetSecTotF(t+1)..      PetF("Whole",t+1) =e= sum(i,PetF(i,t+1));

PetSecTot(t+1)..       P("Whole",t+1) =e= sum(i,P(i,t+1));

LignSup(t+1)..         LIGN("Whole",t+1) =e= LIGN1(t+1)+LIGN2(t+1)+LIGN3(t+1);

LignSecTot(t+1)..      LIGN("Whole",t+1) =e= sum(i,Lign(i,t+1));

WoodSecTot(t+1)..      WOOD("Whole",t+1) =e= sum(i,Wood(i,t+1));

NGSecTot(t+1)..        N("Whole",t+1) =e= sum(i, N(i,t+1));

TotELign(t+1)..        ELIGN(t+1) =e= ELIGN1(t+1)+ELIGN2(t+1)+ELIGN3(t+1);

TotLigCon(t+1)..       TotLign(t+1) =e= TotLign1(t+1)+TotLign2(t+1)+TotLign3(t+1);

TotLig1Con(t+1)..      TotLign1(t+1) =e= conv("Lignite1")*ELIGN1(t+1)+LIGN1(t+1);

TotLig2Con(t+1)..      TotLign2(t+1) =e= conv("Lignite2")*ELIGN2(t+1)+LIGN2(t+1);

TotLig3Con(t+1)..      TotLign3(t+1) =e= conv("Lignite3")*ELIGN3(t+1)+LIGN3(t+1);

TotPetFCon(t+1)..      TotPetF(t+1) =e=
                       conv("PetroleumProducts")*EPET(t+1)+PETF("Whole",t+1);

TotCoalFCon(t+1)..     TotCoalF(t+1) =e= conv("Coal")*ECOAL(t+1)+COALF("Whole",t+1);

TotNGCon(t+1)..        TotNG(t+1) =e= conv("NaturalGas")*ENGAS(t+1)+N("Whole",t+1);

TotLig1ConU(t+1)..     TotLign1(t+1) =l= (1.50-0.40*((ord(t)>2))) * TotLign1(t);

TotLig2ConU(t+1)..     TotLign2(t+1) =l= (1.50-0.40*((ord(t)>2))) * TotLign2(t);

TotLig3ConU(t+1)..     TotLign3(t+1) =l= (1.50-0.40*((ord(t)>2))) * TotLign3(t);
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TotPetFConU(t+1)..        TotPetF(t+1) =l= (1.50-0.35*((ord(t)>2))) * TotPetF(t);

TotCoalFConU(t+1)..       TotCoalF(t+1) =l= (1.50-0.35*((ord(t)>2))) * TotCoalF(t);

TotNGConU(t+1)..          TotNG(t+1) =l= (1.50-0.35*((ord(t)>2))) * TotNG(t);

TotSecCoalFConU(t+1)..  CoalF("Whole",t+1) =l= (1.50-0.35*((ord(t)>2))) * CoalF("Whole",t);

TotCoalDU(t+1)..          COALD("Whole",t+1) =l= (1.50-0.40*((ord(t)>2))) * COALD("Whole",t);

TotWoodU(t+1)..           WOODd("Whole",t+1) =l= (1.50-0.50*((ord(t)>2))) * Wood("Whole",t);

TotLIGNU(t+1)..           LIGN("Whole",t+1) =l= (1.50-0.40*((ord(t)>2))) * LIGN("Whole",t);

CoalFConU(i,t+1)..        CoalF(i,t+1) =l= (1.30-0.10*((ord(t)>2))) * CoalF(i,t);

CoalDU(i,t+1)..           COALD(i,t+1) =l= (1.30-0.10*((ord(t)>2))) * COALD(i,t);

WOODU(i,t+1)..            WOOD(i,t+1) =l= (1.30-0.10*((ord(t)>2))) * WOOD(i,t);

LIGNU(i,t+1)..            LIGN(i,t+1) =l= (1.30-0.10*((ord(t)>2))) * LIGN(i,t);

PETDU(i,t+1)..            PETD(i,t+1) =l= (1.30-0.10*((ord(t)>2))) * PETD(i,t);

PETFU(i,t+1)..            PETF(i,t+1) =l= (1.30-0.10*((ord(t)>2))) * PETF(i,t);

TotLig1ConL(t+1)..        TotLign1(t+1) =g= (0.50+0.40*((ord(t)>2))) * TotLign1(t);

TotLig2ConL(t+1)..        TotLign2(t+1) =g= (0.50+0.40*((ord(t)>2))) * TotLign2(t);

TotLig3ConL(t+1)..        TotLign3(t+1) =g= (0.50+0.40*((ord(t)>2))) * TotLign3(t);

TotPetDConL(t+1)..        PetD("Whole",t+1) =g= (0.50+0.40*((ord(t)>2))) * PetD("Whole",t);

TotPetFConL(t+1)..        TotPetF(t+1) =g= (0.50+0.35*((ord(t)>2))) * TotPetF(t);

TotCoalFConL(t+1)..       TotCoalF(t+1) =g= (0.50+0.35*((ord(t)>2))) * TotCoalF(t);

TotNGConL(t+1)..          TotNG(t+1) =g= TotNG(t)-0.05 *((ord(t)>18))* TotNG(t)-0.05
                          *((ord(t)>28))* TotNG(t);

TotSecCoalFConL(t+1).. CoalF("Whole",t+1) =g= (0.50+0.35*((ord(t)>2))) * CoalF("Whole",t);

TotCoalDL(t+1)..          COALD("Whole",t+1) =g= (0.50+0.40*((ord(t)>2)))*COALD("Whole",t);

TotWoodL(t+1)..           Wood("Whole",t+1) =g= (0.50+0.40*((ord(t)>2))) * Wood("Whole",t);

TotLIGNL(t+1)..           LIGN("Whole",t+1) =g= (0.50+0.40*((ord(t)>2))) * LIGN("Whole",t);

CoalFConL(i,t+1)..        CoalF(i,t+1) =g= (0.70+0.10*((ord(t)>2))) * CoalF(i,t);

CoalDL(i,t+1)..           COALD(i,t+1) =g= (0.70+0.10*((ord(t)>2))) * COALD(i,t);

WOODL(i,t+1)..            WOOD(i,t+1) =g= (0.70+0.10*((ord(t)>2))) * WOOD(i,t);

LIGNL(i,t+1)..            LIGN(i,t+1) =g= (0.70+0.10*((ord(t)>2))) * LIGN(i,t);

PETDL(i,t+1)..            PETD(i,t+1) =g= (0.70+0.10*((ord(t)>2))) * PETD(i,t);
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PETFL(i,t+1)..            PETF(i,t+1) =g= (0.70+0.10*((ord(t)>2))) * PETF(i,t);

GroTotPetDCon..           sum(t,PETD("Whole",t)) =l= Rsrv("PetroleumProducts");

GroTotLig1Con..           sum(t,TotLign1(t)) =l= Rsrv("Lignite1");

GroTotLig2Con..           sum(t,TotLign2(t)) =l= Rsrv("Lignite2");

GroTotLig3Con..           sum(t,TotLign3(t)) =l= Rsrv("Lignite3");

GroTotCoalDCon..          sum(t,COALD("Whole",t)) =l= Rsrv("Coal");

HydroSup(t+1)..           EHYDR(t+1) =e= EHYDRODAM(t+1)+EHYDRORIVER(t+1);

HydroDAMCon(t+1)..        EHYDRODAM(t+1) =l= Rsrv("HydroDAM");

HydroRIVERCon(t+1)..      EHYDRORIVER(t+1) =l= Rsrv("HydroRIVER");

GeothermalCon(t+1)..      EGEO(t+1) =l=  Rsrv("Geothermal");

WindCon(t+1)..            EWND(t+1) =l= Rsrv("Wind");

SolarCon(t+1)..           ESOL(t+1) =l= Rsrv("Solar");

IncEleLig1L(t+1)..        Inc("Lignite1",t+1) =g= IncLow("Lignite1",t+1)*ELIGN1(t);

IncEleLig2L(t+1)..        Inc("Lignite2",t+1) =g= IncLow("Lignite2",t+1)*ELIGN2(t);

IncEleLig3L(t+1)..        Inc("Lignite3",t+1) =g= IncLow("Lignite3",t+1)*ELIGN3(t);

IncEleHydDAML(t+1)..      Inc("HydroDAM",t+1) =g= IncLow("HydroDAM",t+1) *
                          EHYDRODAM(t);

IncEleHydRIVERL(t+1)..            Inc("HydroRIVER",t+1) =g= IncLow("HydroRIVER",t+1) *
                                  EHYDRORIVER(t);

IncElePetL(t+1)..         Inc("PetroleumProducts",t+1) =g= IncLow("PetroleumProducts",t+1) *
                          EPET(t);

IncEleNGasL(t+1)..        Inc("NaturalGas",t+1) =g= IncLow("NaturalGas",t+1)*ENGAS(t);

IncEleCoalL(t+1)..        Inc("Coal",t+1) =g= IncLow("Coal",t+1)*ECOAL(t);

IncEleWndL(t+1)..         Inc("Wind",t+1) =g= IncLow("Wind",t+1)*EWND(t);

IncEleGeoL(t+1)..         Inc("Geothermal",t+1) =g= IncLow("Geothermal",t+1)*EGEO(t);

IncEleSolL(t+1)..         Inc("Solar",t+1) =g= IncLow("Solar",t+1)*ESOL(t);

IncEleNucL(t+1)..         Inc("Nuclear",t+1) =g= IncLow("Nuclear",t+1)*ENUC(t);

IncEleLig1U(t+1)..        Inc("Lignite1",t+1) =l=  IncUp("Lignite1",t+1)*ELIGN1(t);

IncEleLig2U(t+1)..        Inc("Lignite2",t+1) =l= IncUp("Lignite2",t+1)*ELIGN2(t);

IncEleLig3U(t+1)..        Inc("Lignite3",t+1) =l= IncUp("Lignite3",t+1)*ELIGN3(t);

IncEleHydDAMU(t+1)..      Inc("HydroDAM",t+1) =l= IncUp("HydroDAM",t+1)*EHYDRODAM(t);
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IncEleHydRIVERU(t+1)..        Inc("HydroRIVER",t+1) =l= IncUp("HydroRIVER",t+1) *
                              EHYDRORIVER(t);

IncElePetU(t+1)..        Inc("PetroleumProducts",t+1) =l= IncUp("PetroleumProducts",t+1) *
                         EPET(t);

IncEleNGasU(t+1)..       Inc("NaturalGas",t+1) =l= IncUp("NaturalGas",t+1)*ENGAS(t);

IncEleCoalU(t+1)..       Inc("Coal",t+1) =l= IncUp("Coal",t+1)*ECOAL(t);

IncEleWndU(t+1)..        Inc("Wind",t+1) =l= IncUp("Wind",t+1)*EWND(t);

IncEleGeoU(t+1)..        Inc("Geothermal",t+1) =l= IncUp("Geothermal",t+1)*EGEO(t);

IncEleSolU(t+1)..        Inc("Solar",t+1) =l= IncUp("Solar",t+1)*ESOL(t);

IncEleNucU(t+1)..        Inc("Nuclear",t+1) =l= IncUp("Nuclear",t+1)*ENUC(t);

CapEleLign1(t+1)..       ELIGN1(t+1) =e= ELIGN1(t) -
                         ((ord(t)<=30))*DepF("Lignite",t+1)*ELIGN1("2003")-
                         ((ord(t)>30))*Inc("Lignite1",t-29)+Inc("Lignite1",t+1);

CapEleLign2(t+1)..       ELIGN2(t+1) =e= ELIGN2(t)-((ord(t)<=30))*DepF("Lignite",t+1)
                         *ELIGN2("2003")- ((ord(t)>30))*Inc("Lignite2",t-29)+Inc("Lignite2",t+1);

CapEleLign3(t+1)..       ELIGN3(t+1) =e= ELIGN3(t)-((ord(t)<=30))*DepF("Lignite",t+1)
                         *ELIGN3("2003")- ((ord(t)>30))*Inc("Lignite3",t-29)+Inc("Lignite3",t+1);

CapEleHydDAM(t+1)..      EHYDRODAM(t+1) =e= EHYDRODAM(t)-((ord(t)<=40)) *
                         DepF("Hydro",t+1) * EHYDRODAM("2003")-
                         ((ord(t)>40))*Inc("HydroDAM",t-39)+Inc("HydroDAM",t+1);

CapEleHydRIVER(t+1).. EHYDRORIVER(t+1) =e= EHYDRORIVER(t)-((ord(t)<=40)) *
                         DepF("Hydro",t+1) * EHYDRORIVER("2003")-
                         ((ord(t)>40))*Inc("HydroRIVER",t-39)+Inc("HydroRIVER",t+1);

CapElePet(t+1)..         EPET(t+1) =e= EPET(t)-((ord(t)<=30)) * DepF("PetroleumProducts",t+1)
                         * EPET("2003")- ((ord(t)>30))*Inc("PetroleumProducts",t-
                         29)+Inc("PetroleumProducts",t+1);

CapEleNGas(t+1)..        ENGAS(t+1) =e= ENGAS(t)-((ord(t)<=25)) *
                         DepF("NaturalGas",t+1)*ENGAS("2003")-
                         ((ord(t)>25))*Inc("NaturalGas",t-24)+Inc("NaturalGas",t+1);

CapEleCoal(t+1)..        ECOAL(t+1) =e= ECOAL(t)-((ord(t)<=30)) * DepF("Coal",t+1) *
                         ECOAL("2003")- ((ord(t)>30))*Inc("Coal",t-29)+Inc("Coal",t+1);

CapEleWnd(t+1)..         EWND(t+1) =e= EWND(t)-((ord(t)<=25)) * DepF("Wind",t+1) *
                         EWND("2003")- ((ord(t)>25))*Inc("Wind",t-24)+Inc("Wind",t+1);

CapEleGeo(t+1)..         EGEO(t+1) =e= EGEO(t)-((ord(t)<=30)) * DepF("Geothermal",t+1) *
                         EGEO("2003")- ((ord(t)>30))*Inc("Geothermal",t-
                         29)+Inc("Geothermal",t+1);
CapEleSol(t+1)..         ESOL(t+1) =e= ESOL(t)-((ord(t)<=25)) * DepF("Solar",t+1) *
                         ESOL("2003")- ((ord(t)>25))*Inc("Solar",t-24)+Inc("Solar",t+1);

CapEleNuc(t+1)..         ENUC(t+1) =e= ENUC(t)-((ord(t)<=40)) * DepF("Nuclear",t+1) *
                         ENUC("2003")-((ord(t)>40))*Inc("Nuclear",t-39)+Inc("Nuclear",t+1);
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GrossOutputRow(i,t+1)..

              sum(j,Inter(i,j,t+1))+C(i,t+1)+sum(j,Invest(i,j,t+1))+X(i,t+1) =e=
              sum(j,Inter(j,i,t+1))+VA(i,t+1)+ECD(i,t+1)+er(t+1)*ECF(i,t+1)+er(t+1)*M(i,t+1);

GrossOutputCol(i,t+1)..

              Y(i,t+1) =e= sum(j,Inter(j,i,t+1))+VA(i,t+1)+ECD(i,t+1)+er(t+1)*ECF(i,t+1);

GDPconst(t+1).. GDP(t+1) =e= sum(i,VA(i,t+1))+NRH(t+1);

*Environmental Constraints

CO2Emission(i,t)..          GHG("CO2",i,t) =e= EF("Coal","CO2")*(COALF(i,t) + COALD(i,t)) +
                            EF("Lignite","CO2") * Lign(i,t) + EF("PetroleumProducts","CO2") *
                            (PetF(i,t) + PetD(i,t)) + EF("NaturalGas","CO2")*N(i,t);

TotalCO2Emission(t)..       GHG("CO2","Whole",t) =e= EF("Coal","CO2") * ( TotCOALF(t) +
                            COALD("Whole",t)) + EF("Lignite","CO2") * TotLign(t) +
                            EF("PetroleumProducts","CO2") * (TotPetF(t) + PetD("Whole",t)) +
                            EF("NaturalGas","CO2") * TotNG(t);

CH4Emission(i,t)..          GHG("CH4",i,t) =e= EF("Coal","CH4") * (Lign(i,t)+COALD(i,t)) +
                            EF("Wood","CH4") * WOOD(i,t);

TotalCH4Emission(t)..       GHG("CH4","Whole",t) =e= EF("Coal","CH4") *
                            (TotLign(t)+COALD("Whole",t)) + EF("Wood","CH4") *
                            WOOD("Whole",t);

N2OEmission(i,t)..          GHG("N2O",i,t) =e= EF_N2O * (Lign(i,t) + CoalF(i,t) + CoalD(i,t) +
                            WOOD(i,t) + PetF(i,t)+PetD(i,t)+N(i,t));

TotalN2OEmission(t)..       GHG("N2O","Whole",t) =e= EF_N2O*(TotLign(t) + TotPetF(t) +
                            PetD("Whole",t) + TotCoalF(t) + CoalD("Whole",t) + TotNG(t) +
                            Wood("Whole",t));

TotalGHG(i,t)..             GHG("Whole",i,t) =e= GHG("CO2",i,t) + GHG("CH4",i,t) +
                            GHG("N2O",i,t) + GHGElec(t)*E(i,t) / E("Whole",t);

GHGElectricity(t)..         GHGElec(t) =e= EF("Coal","CO2")*(TotCOALF(t)-COALF("Whole",t))+
                            EF("Lignite","CO2") * (TotLign(t) - Lign("Whole",t))+
                            EF("PetroleumProducts","CO2") * (TotPetF(t)-PetF("Whole",t))+
                            EF("NaturalGas","CO2")*(TotNG(t)-N("Whole",t))+
                            EF("Coal","CH4")*(TotLign(t)-Lign("Whole",t))+
                            EF_N2O*(TotLign(t) - Lign("Whole",t) + TotPetF(t) - PetF("Whole",t) +
                            TotCoalF(t)-CoalF("Whole",t)+TotNG(t)-N("Whole",t));

GrandTotalGHG(t)..          GHG("Whole","Whole",t) =e= GHG("CO2","Whole",t) +
                            GHG("CH4","Whole",t) + GHG("N2O","Whole",t);

ElectricityPrice(t+1)..     pelec(t+1) =e= tdm*( cd("Lignite1",t+1)*conv("Lignite1")*ELIGN1(t+1) +
                            cd("Lignite2",t+1)*conv("Lignite2")*ELIGN2(t+1) +
                            cd("Lignite3",t+1)*conv("Lignite3")*ELIGN3(t+1)+
                            cf("PetroleumProducts",t+1)*conv("PetroleumProducts")*EPET(t+1)+
                            cf("Coal",t+1)*conv("Coal")*ECOAL(t+1)+
                            cf("NaturalGas",t+1)*conv("NaturalGas")*ENGAS(t+1)+
                            cf("Nuclear",t+1)*ENUC(t+1)+
                            ce("HydroDAM",t+1)*EHYDRODAM(t+1) +
                            ce("HydroRIVER",t+1)*EHYDRORIVER(t+1)+
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                              ce("Lignite",t+1)*ELIGN(t+1)+
                              ce("PetroleumProducts",t+1)*EPET(t+1)+
                              ce("Coal",t+1)*ECOAL(t+1)+
                              ce("NaturalGas",t+1)*ENGAS(t+1)+
                              ce("Wind",t+1)*EWND(t+1)+
                              ce("Geothermal",t+1)*EGEO(t+1)+
                              ce("Solar",t+1)*ESOL(t+1)+
                              ce("Nuclear",t+1)*ENUC(t+1)+
                              ci("Lignite",t+1)*ELIGN1(t+1)+
                              ci("Lignite",t+1)*ELIGN2(t+1)+
                              ci("Lignite",t+1)*ELIGN3(t+1)+
                              ci("HydroDAM",t+1)*EHYDRODAM(t+1)+
                              ci("HydroRIVER",t+1)*EHYDRORIVER(t+1)+
                              ci("PetroleumProducts",t+1)*EPET(t+1)+
                              ci("NaturalGas",t+1)*ENGAS(t+1)+
                              ci("Coal",t+1)*ECOAL(t+1)+
                              ci("Wind",t+1)*EWND(t+1)+
                              ci("Geothermal",t+1)*EGEO(t+1)+
                              ci("Solar",t+1)*ESOL(t+1)+
                              ci("Nuclear",t+1)*ENUC(t+1))
                              / E("Whole",t+1);

LignitePrice(t+1)..           plign(t+1) =e= ( cd("Lignite1",t+1)*TotLign1(t+1) +
                              cd("Lignite2",t+1)*TotLign2(t+1) + cd("Lignite3",t+1)*TotLign3(t+1) ) /
                              TotLign(t+1);

CoefficientForElec(t+1).. ForElecCoef(t+1) =e=  tdm*(
                              cf("PetroleumProducts",t+1)*conv("PetroleumProducts")*EPET(t+1)+
                              cf("Coal",t+1)*conv("Coal")*ECOAL(t+1)+
                              cf("NaturalGas",t+1)*conv("NaturalGas")*ENGAS(t+1)+
                              cf("Nuclear",t+1)*ENUC(t+1)+
                              0.75*ci("Lignite",t+1)*ELIGN1(t+1)+
                              0.75*ci("Lignite",t+1)*ELIGN2(t+1)+
                              0.75*ci("Lignite",t+1)*ELIGN3(t+1)+
                              0.50*ci("HydroDAM",t+1)*EHYDRODAM(t+1)+
                              0.75*ci("HydroRIVER",t+1)*EHYDRORIVER(t+1)+
                              0.75*ci("PetroleumProducts",t+1)*EPET(t+1)+
                              0.75*ci("NaturalGas",t+1)*ENGAS(t+1)+
                              0.75*ci("Coal",t+1)*ECOAL(t+1)+
                              0.75*ci("Wind",t+1)*EWND(t+1)+
                              0.75*ci("Geothermal",t+1)*EGEO(t+1)+
                              0.75*ci("Solar",t+1)*ESOL(t+1)+
                              ci("Nuclear",t+1)*ENUC(t+1)
                              ) /(pelec(t+1)*E("Whole",t+1));


CoefficientDomElec(t+1)..           DomElecCoef(t+1) =e= (1-ForElecCoef(t+1));


SectoralEnergyCostD(i,t+1)..        ECD(i,t+1) =e=
                                    DomElecCoef(t+1)*pelec(t+1)*E(i,t+1)+cd("PetroleumProducts",t
                                    +1)*PetD(i,t+1)+plign(t+1)*Lign(i,t+1)+cd("Coal",t+1)*CoalD(i,t
                                    +1)+cd("Wood",t+1)*Wood(i,t+1);

SectoralEnergyCostF(i,t+1)..        ECF(i,t+1) =e=
                                    ForElecCoef(t+1)*pelec(t+1)*E(i,t+1)+cf("NaturalGas",t+1)*N(i,t
                                    +1)+cf("PetroleumProducts",t+1)*PetF(i,t+1)+cf("Coal",t+1)*Coa
                                    lF(i,t+1);
```

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Objective..                             Obj =e=
                                        sum( (i,t)$(ord(t)<=38),delta(t)*(theta(i)*( scd(i)*log(CGD(i,t)) +
                                        scg(i)*log(CGF(i,t)) )) ) + sum(i,((1/(1+delt))**38)*(1+pgr)*(1 /
                                        (1- (1/(1+delt)) * (1+pgr) ) )*( theta(i)*(
                                        scd(i)*log(CGD(i,"2040")) + scg(i)*log(CGF(i,"2040")) ) )) ;
*=====================================================================
Model MultiSectorGE/all/;
OPTIONS  DECIMALS = 8, ITERLIM =10000000, limrow=5, reslim=10800000000, domlim=100;
MultiSectorGE.optfile=1;
MultiSectorGE.SCALEOPT = 1;
Solve MultiSectorGE using nlp maximizing Obj;
*=====================================================================
$include 'C:\Users\dell\Documents\Doktora\Tez.Modeller.Defense\Two.Sector\IncludeFiles\OutputMultiV8.inc'
*=====================================================================
Execute_Unload "BaseCaseV1.gdx";
```

CURRICULUM VITAE

PERSONAL INFORMATION

Surname, Name	Kat, Bora
Nationality	Turkish
Date and Place of Birth	17.11.1979, Midyat
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EDUCATION

2002 – 2005	M.Sc. in Industrial Engineering, METU, Ankara
1997 – 2002	B.Sc. in Industrial Engineering, METU, Ankara
1996 – 1997	Eskişehir Atatürk High School, Eskişehir
1994 – 1996	Eskişehir Fatih Science High School, Eskişehir

WORK & TRAINING

2006 –	Scientific Programs Expert, The Scientific and Technological Research Council of Turkey (TÜBİTAK), Ankara, Turkey
Aug -Dec 2009	Short-term Secondee, European Science Foundation, Strasbourg, France
2002 -2006	Research and Teaching Assistant, Department of Industrial Engineering, METU, Ankara, Turkey
2005- 2006	Advisory to UNFCC Implementation on Energy Scenarios and Analyzing the Energy Model and the Outputs. Under the UNDP-GEF Project "Enabling the activities for preparation of Turkey's initial national communication to the UNFCCC", Ankara, Turkey
February 2006	Training Seminar in Enerdata, "Evaluation of Energy Efficiency Trends and Potential" and "End Use Energy Modelling", Grenoble, France

PUBLICATIONS

Paper

Kat B., Avşar Z.M., "Using Aggregate Fill Rate for Dynamic Scheduling of Multi-Class Systems", Annals of Operations Research, Volume 182, Number 1, 87-117, DOI: 10.1007/s10479-009-0535-2

Proceedings

Kat B., Güven Ç., Voyvoda E., "A General Equilibrium Energy-Economy Model for Turkey", Proceedings, EcoMod 2008: International Conference on Policy Modelling, Berlin, 2008

Kat B., Solyalı O. "A bicriteria single allocation hub location problem", Proceedings of the 27th National Meeting on Operational Research and Industrial Engineering, İzmir, Turkey, 2007.

Kat B., Avşar Z.M., "Heuristics for Dynamic Scheduling of Multi-Class Base-Stock Controlled Systems", Proceedings, 5th International Conference on 'Analysis of Manufacturing Systems – Production Management', Zakynthos Island, Greece, 2005.

Kat B., Avşar Z.M., "Alternative Policies by Heuristics for Dynamic Scheduling of a Two-Class Base-Stock Controlled System", Proceedings of the 24th National Meeting on Operational Research and Industrial Engineering, Gaziantep, Turkey, 2004.

Honours & Awards

1997-2002	B.Sc. Scholarship, METU

Miscellaneous

Languages	English (fluent), German (beginner), French (beginner)
Memberships	Operational Research Society of Turkey, Chamber of Mechanical Engineers, Editorial Board of Industrial Engineering Journal (Turkish)
Interests	Cinema, Table Tennis, Football, Three Cushion Billiards