AN INTERTEMPORAL AND SPATIAL NETWORK MODEL FOR TURKISH ENERGY SYSTEM

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ABSTRACT

An Intertemporal and Spatial Network Model for Turkish Energy System

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Turkey, as a recent signatory to the United Nations Framework Convention on Climate Change (UNFCCC) has to adopt policies to restrict greenhouse gas emissions at a time when energy demand is increasing rapidly. We report on an intertemporal, spatial network model representing the energy system that seeks to address the difficult trade-offs involved. We compute and optimal mix of fuels and technologies; considering efficiencies and investments in generation and transmission. The model allows analysis of emissions and investment decisions to attain set targets. Extensions allowing the study of dependency on fossil fuels and imports are also discussed.

Keyword: Energy Modeling, Power Sector Investment

ÖZ

Türkiye Enerji Sistemi için Dinamik ve Coğrafi Bir Ağ Modeli

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Birleşmiş Milletler İklim Değişikliği Çerçeve Sözleşmesi'ni (UNFCCC) yeni imzalayan bir ülke olarak Türkiye enerji talebinin hızla arttığı bir zamanda, sera gazı salımını kısıtlayıcı politikaları benimsemek durumunda. Bu çalışmada enerji sistemini dönemler halinde ve bölgesel nitelikte simgeleyen bir ağ modeli geliştirip, bu model vasıtasıyla konunun içerdiği bazı zor kararları da irdeliyoruz. Teknolojilerin verimliliği ve elektrik üretim ve dağıtım yatırımlarını de hesaba katarak, yakıtların ve tüketim/çevrim teknolojilerinin en iyi karışımını bulmayı hedefliyoruz. Geliştirilen model belirlenen hedeflere ulaşma neticesinde ortaya çıkacak gaz salım miktarlarını ve gerekecek yatırım kararlarını da çözümlemeye olanak sağlıyor. Fosil yakıtlara ve ithal enerji kaynaklarına olan bağımlılık da tartışılıyor.

Anahtar Kelimeler: Enerji Modelleri, Elektrik Sektörü Yatırımları

To my family and my love…

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

Energy is fundamental to the modern life. From the light bulbs that illuminate our homes to the engines that move our cars; anything that we consider indispensable for the quality of our lives depend, in any case, on energy. All these entities continue to be a part of our modern society with the help of a tremendously large system that comprises exploration and extraction of resources, conversion into useful forms of fuels, production of heat; generation, transmission and distribution of electricity, and transformation of heat and electricity into mechanical energy. Ability to control, transmit and convert energy is the essence of what we know as the industrial age. Perhaps, the gain from industrialization was so much that the coming of two problems was not noticed until recently.

1973 Oil Crisis had forced the countries to reconsider their approaches to the energy concept. The strict dependency on oil had shown its effects in the global economy. This resulted in seeking countersteps to lessen the oil dependency, increased interest in new sources of energy and absolute necessity for developing more efficient ways of producing and consuming energy. The very first efforts to develop large scale energy models for planning purpose began then. The developments in the computer science allowed proper representations of energy systems and provided solutions for important decisions.

Now the world is facing another crisis related to energy that is not due to political or natural restrictions on energy resources, but on the side effects of energy generation and consumption activities. Global warming and resulting climate change is an accepted phenomenon which is human-caused.

> *Global atmospheric concentrations of carbon dioxide, methane and nitrous oxide have increased markedly as a result of human activities since 1750 and now far exceed pre-industrial values determined from ice cores spanning many thousands of years. The global increases in carbon dioxide concentration are due primarily to fossil fuel use and land-use change, while those of methane and nitrous oxide are primarily due to agriculture.* [1]

The major concern now and in the coming future will be on the control and reduction of these gases which are named greenhouse gases (GHG); and the main tool to accomplish this will be using clean technologies for energy generation. Environmental effects should be considered in any research, plan and decision regarding energy; and be among the objectives of policy building efforts. No doubt, this requires international commitment as this problem has already gone beyond country borders. United Nations Framework Convention for Climate Change (UNFCCC) is an international act aiming to realize this international collaboration. It is also the basis for Kyoto Protocol which also has certain legal measures. Turkey is a signatory to the UNFCCC since 2004 and has to implement the commitments that it undersigned. As a part of these, Turkey released its first National Communication in February 2007.

On the other hand, Turkey is not a party to the Kyoto Protocol but this status is increasingly discussed within the country. *Should Turkey sign the protocol? Should base year be other than 1990? What are Turkey's current status in terms of emissions and clean energy sources? What plan should Turkey build and follow in order to attain set emission goals?* These questions are asked everywhere, but proper policies regarding the issue have not yet been developed in full scale. This study has started under these circumstances during the UNDP project in which we took part in the preparation of the aforementioned national communication. It was observed that Turkey needed country specific, full scale energy models to use in policy building and analysis.

Consequently, this study aims at developing such a model to address the first problem, policy building. Here we develop a basic intertemporal and spatial network model representing the sources of energy, demands for energy and the conversion, transportation and consumption activities between them. We consider investment decisions especially in the power sector and calculate resulting gas emissions from energy production and consumptions.

In Turkey, employing models in making energy decisions has had certain shortfalls. Currently Turkey employs three models: MAED for energy demand projections, BALANCE for quantity price simulations and WASP for electricity generation sector investment. The concern here is of course not the quality of the models employed, as they are all well known models which serve their purposes quite well.

The first shortfall of the practice is that the models employed by Turkey are not specific to Turkey. They have the potential to reflect certain country specific features with adjustments in them but none of them were developed considering the needs of Turkey. For instance, none of these models addresses the key questions like "*Should Turkey utilize its abundant lignite resources instead of developing its strategy in a way that it depends heavier on imported natural gas?*" or *"What will be the effect of reducing CO2 emissions levels to the national economy?"*.

A second shortfall is that the employers of the model have limited insight about the rationale of these models and they carry out their studies with very limited information on the system. The studies with these models have been done in strict time windows. There is no database which is built to supply information to them. Therefore the information used in the models is not updated on a regular basis. As a result they are not adequate representatives of the Turkish energy system.

A third unfortunate shortfall is that, the insufficient interest of the governing bodies is shared by the academic society. To demonstrate, the first and the last large scale model for Turkey was developed in 1977 by the Bogazici University.

The final and the most significant shortfall is that these models are not employed to develop or evaluate energy policies. In the current practice, these models are employed occasionally, mainly for certain reporting duties. For instance the BALANCE model is only used in a study for the World Bank in 2002 and for a second time during the preparation of the first National Communication to the UNFCCC.

Under these circumstances we propose an intertemporal and spatial network model for the Turkish energy system. The model we developed has the potential to provide answers to various key questions about the energy system. However this study does not aim to address such questions. The major contributions of it would be:

- Proposing a working model of the Turkish energy system which has a fair representation power
- Exercising with this model by calibrating it with the actual system data and demonstrating the outcomes

The study does not aim to propose an investment or development strategy for the energy system, but rather provides a tool for doing them. It lacks important macroeconomic and environmental properties. In its current status it does not provide any relation with the entire economy beyond the energy system border;

and it does not include the economic, social or natural aspects of the environmental effects. Nevertheless it brings a fundamental model representing the energy system structure which possesses the potential of being developed and supplied with macroeconomic and environmental tools to address various key questions.

The thesis is organized under five chapters, whose contents are briefly summarized below.

In Chapter 2, we present a review of previous studies on the same topic, and report on a similar previous study for Turkey.

In Chapter 3, we describe the Turkish energy system. Energy resources of the country with production amounts, capacities and reserves are presented. The power system is discussed. Finally the demand side of the energy system and resulting environmental effect is reported. At the same time the energy system network as it is modeled in this study is illustrated.

In Chapter 4, we introduce the aforementioned mathematical model. The parameters, variables, key assumptions, model constraints and the objective function are presented.

In Chapter 5, we present and discuss the results obtained from the base case solution of the model; we further discuss the model results under one stated policy goal.

We conclude our study and briefly comment on further study areas regarding this topic.

CHAPTER 2

LITERATURE SURVEY

The energy models have their roots, as explained previously, in the 1973 oil crisis. Since then numerous models with different characteristics have been developed. There is an abundant literature on the topic, but most of these studies can more or less be related to some basic models (and approaches) that were developed around 2-3 decades ago. Here, we will present a brief classification of energy models, introduce and explain the most well-known of these models, discuss a few studies on the Turkish energy system and conclude by positioning the model we propose in the models classification and comparing with other studies on Turkish energy system.

There are a number of criteria according to which the energy models can be classified. The reader may refer to Kavrakoğlu [2], Brock and Nesbitt [3] and van Beeck [4] for certain classifications. Almost all the time these criteria are, in fact, interrelated. Here we will use a selection of those criteria: *purpose*, *approach*, *methodology* and *coverage*.

- **Purpose.** The energy models are developed and employed to serve various purposes [5]. Some of these are:
    - Demand forecasting. Projections of demands are essential for policy development and investments planning. Some energy

models predict the future demand relying mostly on econometric techniques.

- Project appraisal. Energy models can be used to evaluate the energy projects.
- Sector optimization. These models can be developed and used for optimizing a sector's (i.e. oil refining) performance and minimizing sectors costs.
- Analytical integration of sectors. These models enable one to study the cross impacts of these sectors by providing multisectoral, full views of the energy systems.
- Policy analysis. Energy models often assist decision makers as they are used to assess the likely consequences of a policy measure.
- Assessment of environmental impact. These models often enable interaction between the energy system and the environment and they are used for predicting and assessing the impacts of future energy scenarios.

Along with these specific purposes, they may be classified more generally. Energy models are used to *predict/forecast* the future or *explore* it under different measures and scenarios.

- **Approach.** Two types of approaches can be named here. The *bottom-up* approach is the engineering view. It is independent of the market behavior, describes the technologies in detail, uses disaggregated and detailed data, defines output by technology, powerful in addressing resource supply but not demands and disregards the interaction between energy sectors and the rest of the economy. The *top-down* approach is the economic view. It is based on observed market behavior, does not explicitly represent technologies, use aggregated data, defines the output in terms of a production frontier, powerful in addressing demand but not supply and considers the economic system often neglecting necessary detail in energy sector. [4] Of course the modeling practice is not limited to these two exclusive approaches. Many models employ a *hybrid* approach, frequently presented as model components (i.e. energy sector network, demand forecast, and macroeconomic components).

– **Methodology.** *Econometric* models use aggregated data of historical market behavior and forecast future behavior, mostly demands, by using this data. *Macroeconomic* models focus on the entire economy and the intersectoral interactions. They do not represent technologies or system structure. *Equilibrium* models may be divided into two – partial and general. Partial equilibrium models consider equilibrium in certain markets. For instance, they may represent the system as a network and seek equilibrium on the end-use demand side considering costs vs. demand for energy products; and on the resource supply side considering costs vs. supply of energy resources. General equilibrium models seek simultaneous market equilibrium in all markets. Optimization models optimize the costs of energy extraction, conversion, transportation and investments subject to certain given parameters. They are formulated as linear programming (LP), nonlinear programming (NLP) and mixed-integer programming (MIP) models. They are employed for policy building and investment planning purposes. Simulation models are descriptive models that reproduce the system operations and rationale.

– **Coverage.** There are there dimensions of coverage – time, geographical and sectoral. Considering time coverage the energy models can be classified as *static* (single time period) and *dynamic*. Dynamic models have a time horizon of short (up to 5 years), medium (up to15, 20 years) or long term (beyond 20 years). The geographical coverage ranges from *local* (city, municipality), *national*, *regional* (i.e. Middle East) to *global*. Finally the sectoral coverage can be viewed in two dimensions. Models can contain a *single sector* or *multiple sectors* in the energy context; or go beyond the energy sector and include rest of the *economy*.

Now we will introduce some fundamental energy models. Energy modeling studies at the Brookhaven National Laboratory (BNL) constitute an important portion of the model development practices. The most basic of the models developed by the BNL is the Brookhaven Energy System Optimization Model (BESOM). BESOM is an optimization model which employs a Reference Energy System (REF). A RES is a directed graph representation of the energy system which shows the flow of energy from resources, through the set of conversion and transportation activities, to the demand sectors. A simple RES is shown in Figure 2.1. BESOM is formulated as a linear programming model whose objective function may be selected as minimization of system costs, minimization of consumed resources or minimization of emissions. The model exogenously accepts projected supplies and demands, and resource and activity costs; and comes up with an optimal consumption bundle and investment plan subject to capacity, thermal loss and peak electricity load constraints. The model can be employed on a local or national scale. The time span is one period, thus it is a static model [6] [3].

Dynamic Energy System Optimization Model (DESOM) is the dynamic counterpart of BESOM. It is actually a sequence of static (single time) models which are solved individually and are linked by capacity transfers and resource availabilities. Cherniavsky et al. [7] presents a detailed description of DESOM.

Time-Stepped Energy System Optimization Model (TESOM) has replaced the above BNL models. It relies on the RES representation like BESOM and DESOM. It is a single region model, thus has not the capability to incorporate multiregional issues like spatial distribution of resources and conversion facilities, and interregional distributions [8].

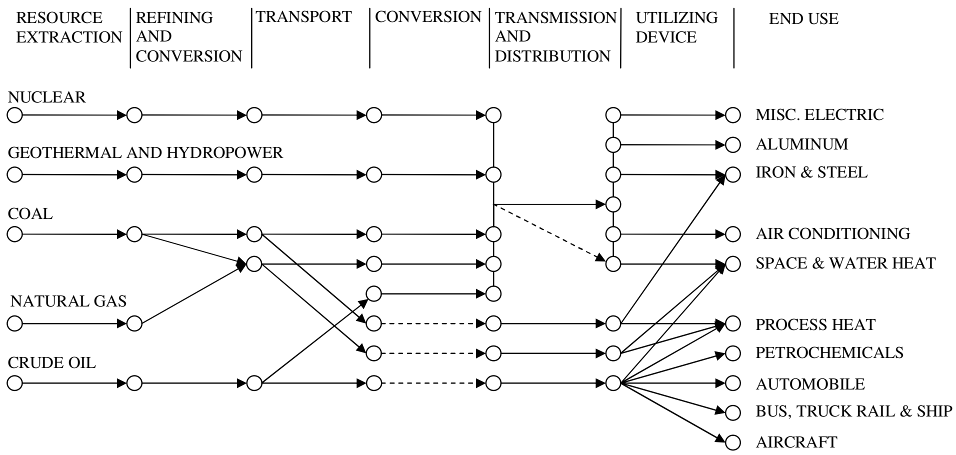


Figure 2.1 Reference Energy System (source: [9])

These BNL models were linear optimization models that sought system-wide optimization by mostly cost minimization. Some other group of early models had a different purpose and scope as they included non-energy sectors of the economy providing, at least, a one way linkage between energy and economics. They relied on inter-industry transactions of input/output type. One of these input/output models is Hudson and Jorgenson model. The model includes 9 industrial sectors of which 5 are energy sectors (coal, crude oil and natural gas production, refining, and electric and gas utilities). The industry sectors take intermediate goods from each other, take imports, take capital and labor services and turn them into energy and non-energy consumption goods. Producers' and consumers' behavior is modeled. This econometric model; given prices of inputs, productivities and price-possibility relations, determines final goods and intermediate inputs, consumptions and investments. This model is further developed by Hoffman and Jorgenson [9] in a way that id combines the input/output, inter-industry transactions methodology with the detailed process representation of RES and optimization methodology.

Shortly after the oil crisis the U.S. government started the Project Independence with the aim for achieving energy independence. Several studies were carried out;

as a result Project Independence Evaluation System (PIES) model came to life [10] [11]. PIES was designed to evaluate the impact of alternative policies. The model was a compound of interrelated models. It had a demand module that operated with an econometric rationale and relate the demands to prices. So different from the BNL models above, it assumed that the demand for the energy form was dependent on the price of it (own price elasticity), and not only on the price of the said fuel, but also on the price of other competing fuels (cross-price elasticity). It used linear programming to represent the energy flow (RES) and simulation (iterative approach) to equilibrate supply and demand at the end nodes. Figure 2.1 illustrates the econometrically determined demand function, step function approximation to the supply and the iteration procedure. The model was an early example of partial equilibrium models. The reader may refer to Brock and Nesbitt [3] for detailed explanation of the model structure.

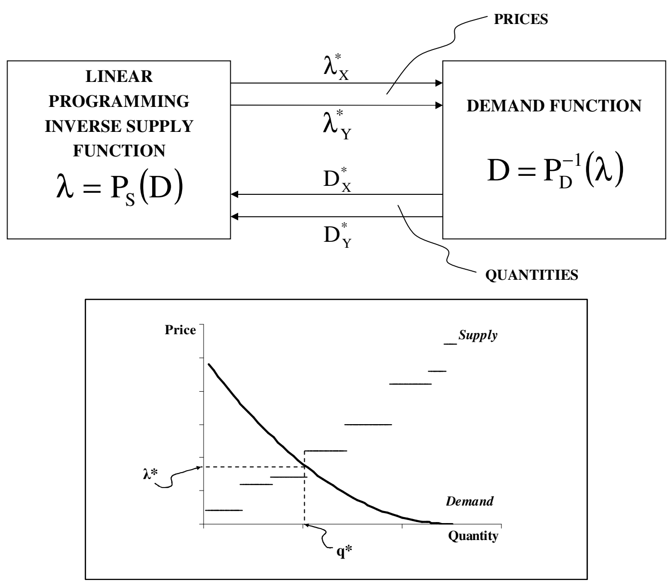


Figure 2.2 Supply / Demand Balance Partial Equilibrium (source: [3]

The PIES model has evolved into a number of other models. It is followed by Midterm Energy Forecasting System (MEFS) and then Intermediate Future

Forecasting System (IFFS) [12] [13]. The last step in this sequence was the National Energy Modeling System (NEMS). NEMS uses an iterative problem oriented approach, has a modular structure that enables independent development of each module, integrates the bottom-up and top-down approaches and gives outputs of key importance (projections of middle term future) but no plan to achieve certain objectives. So it is a dynamic, multisectoral, multiregional model that provides a two way linkage between energy sector and economy, and is predictive in purpose [14]. NEMS is fully documented on the Department of Energy (DOE), Energy Information Agency (EIA) website [15].

Beyond these above predictive economic models, certain optimization models that provide energy economy interaction and economic approach to demand were proposed. Energy Technology Assessment (ETA) is an optimization model. Unlike BESOM and it's counterparts it does not take the demands as given but treat them in a price responsive way; and it is not built on a RES but has an aggregated view of energy sector. It separates electric energy and non-electric energy forms in demand with own and cross price elasticities. Given a number of capacity constraints and structural constraints, it optimizes by maximizing the sum of producers' and consumers' surpluses (or equally minimizing energy system costs). The model is nonlinear, dynamic (75 years) and is applied on national scale [11] [16].

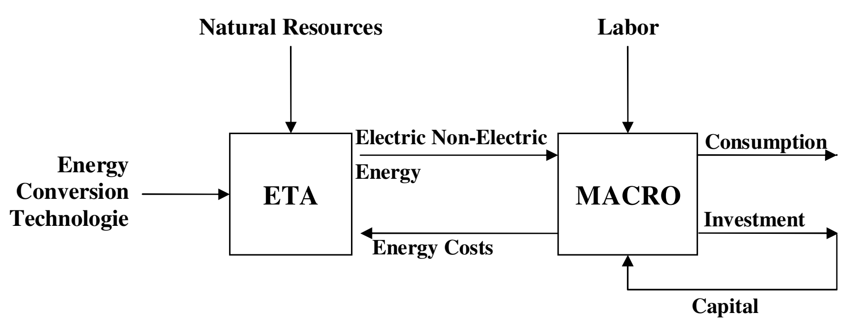


Figure 2.3 ETA-MACRO, Inputs and Outputs (source: [17])

ETA-MACRO is a modified version of the ETA model. It simulates the market economy. The energy sector in ETA supplies the energy that the production system of MACRO uses. MACRO calculates the consumption, investment (capital stock and energy payments). It uses capital, labor and energy (two forms) as substitutable production factors. It employs a constant elasticity of substitution type production function, considering substitution between energy and labor-capital pair [11] [17]. Figure 2.3 demonstrates the procedure of ETA-MACRO.

Another model that experienced a similar evolution sequence is the Market Allocation (MARKAL) model that is developed by the International Energy Agency (IEA) in the Energy Technology Systems Analysis Programme (ETSAP). It is a linear programming model. It is built on RES, therefore comprises detailed energy related activities from resource extraction to end use, but has no linkage to the rest of the economy. It is a dynamic model and it minimizes the discounted total system cost over the planning horizon. It is both applied on a local and national scale. Like most models it is modified to add certain capabilities and it is often mentioned as the MARKAL family of models. Stochastic MARKAL – following a hedging strategy adaptive to scenarios, Multiple Regions MARKAL – allowing emissions trading among countries, MARKAL-ETL – related with promoting new technologies are in this family. The reader may refer to ETSAP website [18] for model documentation. The most well-known type of MARKAL is the MARKAL-MACRO.

MACRO is developed by BNL. It is a macroeconomic model that takes capital, labor and energy service as inputs, turns into aggregated output by applying a CES type production function, determines the consumption, investment and the costs of energy (from MARKAL) by maximizing the discounted logarithm of consumer utility expresses by the consumption. This model allows two-way linkage between economy and energy sector. From the approach point of view it combines the engineering (bottom-up) approach of MARKAL with economic (top-down) approach of MACRO [4] [19].

There are several other models, similar to the ones above. For instance models developed by Stanford Research Institute (SRI), SRI-Gulf, SRI-National and SRI World Energy Model are partial equilibrium models. They include a spatial network representation of the energy system. They find supply/demand balance through a similar procedure like PIES. It begins with an initial guess of equilibrium quantity, finds the price of the resource depending on this quantity, adjusts the demand using this price and continues until a desired level of convergence is achieved. Brock and Nesbitt [3] describes these models their formulation and algorithms in detail. Models like LEAP, that employ the Generalized Equilibrium Modeling System (GEMS) approach are similar to the SRI models but they reflect a more advanced representation of the economy and economic rationale but a limited representation of the energy sector, end uses and supply technologies. The builder of GEMS, Nesbitt [20], describes the GEMS in detail.

Similar studies because of similar compelling reasons have emerged in Europe, too. The very first modeling studies carried out by individual countries have been replaced by continental efforts to develop energy models. The overriding concern was to develop models to assess the energy demand in short to medium term and provide optimal policies for controlling material flows and investments. As a result, several models were introduced and employed.

Energy Flow Optimization Model (EFOM) is at the center of these models. It is a linear programming model which is constructed on a detailed multisectoral energy network (RES) and aims at investigating possible investment and supply polices subject to given end use demands. It is often linked to a demand module from which it imports these demand parameters. The model is supplied with a database of techno-economic and capacity data. The geographical/time coverage may range from single country/static to multiple countries/dynamic, but the interaction between the energy sector and the entire economy is not considered. It reports energy balances, capacity investments; and the overall energy system costs which it minimizes [21] [22]. The reader may refer to Finon [23] for a longer description of the EFOM model.

The EFOM model has been modified to serve more specific needs. One commonly known extension of the model is EFOM-ENV which again an optimization model comprising energy environment interactions and enabling policy analysis in environmental topics like CO_2 reduction. Like the original one EFOM-ENV does not include the economy beyond the energy sector [4].

Another group of models were developed by the International Institute of Applied Systems Analysis (IIASA). These models are developed as modules that are linked to each other to form an aggregate model. At the center of the model, there is a linear programming type of optimization model named MESSAGE. It provides a detailed explanation of the energy resources, conversion technologies and end uses. It minimizes the discounted sum of energy related costs over the planning horizon of 50 years, and comes up with investment plans and optimized supply strategy. These plans are used by the input-output model IMPACT that calculates the costs of proposed investment plans. The MACRO module takes the supply strategy (imports) and the investment costs, checks their balance with the economic facts, and calculates the investment and consumption rates. These are finally utilized by the MEDEE model to provide the necessary demand data to the MESSAGE. The applications include national and global levels. These are not realized simultaneously but iteratively allowing user intervention [24] [25].

PRIMES model is developed by the national Technical University of Athens. It simulates market equilibrium like the NEMS model. It covers the European Union member countries (EU-15 area), thus it is a regional model with multiple countries. It is a static model but can be solved iteratively like DESOM if necessary inter-period relationships are defined. The model also includes a representation of the energy network. Its design is modular like NEMS which enables partial or full use of the model. The outputs are forecasts which enable the model to use for predictive purposes [26]. For a description and comparison of European energy models the reader may refer to Ercan [27]

For a compilation of energy models and applications the reader may refer to books by Bunn and Larsen [28], Brock and Nesbitt [3], Lev [29], Searl [30], and Kavrakoğlu [31]; for a review of model mathematics and formulation, to the book by Brock and Nesbitt [3]; and for a basic comparison of formulations, to the article by Weyant [32].

The modeling studies in Turkey a history of around three decades. However, the current practice does not include country specific models to build and analyze energy policies; but just implement modeling for the purpose of reporting to foreign institutions like UNDP and World Bank. The first comprehensive energy model that is developed for Turkey is the Boğaziçi Üniversitesi Türkiye Enerji Modeli (BÜTEM) by Kavrakoğlu et al. [2]. BÜTEM was an optimization model. They have developed the model based on a RES for the Turkish energy system. The model is built around a linear network but the model is formulated as an MIP. BÜTEM is a dynamic model which covers a time span of 24 years (1977-2000). It covers all available fuels, aggregated and individual (power plant projects) conversion technologies, and four demand sectors (residential, agriculture, transportation, aggregated industry – heat and electricity separated). The model gets the demands exogenously and they are not price related. Major constraints ware structural (network defining) constraints, material flow balance equations, capacity constraints, expansion limitations, minimum energy requirements by demand sectors, peak load satisfaction for power sector investment and financial limits for investments. The country is modeled as a single region. The model is solved for two different objectives – minimization of the sum of discounted system costs and minimization of total resources supplied.

The previously mentioned ETA and ETA-MACRO model has also been implemented in Turkey. The Turkish ETA by Arıkan [33] and ETA-MACRO type model to investigate energy planning under import restrictions by Güven [34] are the first of these studies. A number of studies that are based on Güven [34] include Kumbaroğlu [35] and Arıkan et al. [36]. Energy modeling with economy interaction and environmental considerations were considered in theses by Kumbaroğlu [35] [37], and Arıkan et al. [36]. Finally, again originating from the preparation studies for the National Communication to the UNFCCC, study by Telli et al. [38] is a very recent example of CGE modeling for energy and environmental policy evaluation. The model investigates the implementation of various policy instruments like taxation and pollution penalties and evaluates the socioeconomic impacts of a number of policy scenarios. The model is built around 10 aggregate sectors, 4 of which are energy producing distributing sectors; and has a time span of 15 years (2006-2020).

To sum up, there is a rich literature of energy modeling applications that are evolved and accumulated around a group of fundamental approaches. The model we propose in this study employs one of the fundamental approaches. It is an optimization model which is formulated as MIP and aims at minimizing the discounted sum of energy related expenses. So, the model is of exploratory purpose and specifically it aims to find an optimal mix of consumed energy resources along with a plan in capacity expansions, power sector investments (generation and transmission) and calculates the resulting gas emissions for 6 gases. The model includes 17 energy resources (5 primary resources; 9 secondary fuels, electricity and 4 renewables) and 11 demand sectors (7 are industrial subsectors). It divides the country into 3 regions and the time span is 18 years from 2003 to 2020.

In comparison with the similar study, BÜTEM, the model we propose has certain similarities and differences. The similarities include the methodology, employment of MIP formulation, exogenous demands, purpose, objective (except resource minimization), most of the constraints (except financial limits) and viewing certain investments as projects and modeling accordingly. The most significant difference is that our model has spatial characteristics as it divides the country into 3 regions and includes geographical distribution of resources, conversion facilities and demand sectors. It is constructed around a different RES for Turkey which is mainly taken from Conzelmann and Koritarov [39]. It includes a very simplified structure to allow transmission investments. It treats electricity and fuels as imperfect substitutes but fuels, among themselves, as perfect substitutes so it does not define minimum limits for the consumption of fuels (except transportation sector). It includes more fuel types and more demand sectors; however the end use differentiation is not detailed as in BÜTEM. It has a flow-stock structure and represents the end use capital stock. Finally the model calculates the resulting emissions for 3 GHG gases and 3 other polluting gases.

CHAPTER 3

TURKISH ENERGY SYSTEM

This chapter begins with introductory information on the Turkish energy system. It is followed by sections in which the current status (as of the base year 2003) of the system is summarized first, and then the model we propose for Turkey is presented with explanations and illustrations. There will be a complete list of resources for the quantities and costs mentioned here and used in the model in the Appendix D.

The energy system and the corresponding model illustration are viewed under five major sections. The first section describes the geographical regions. In the model, the energy system is handled in three geographical regions, and all resources, conversion facilities and demand sectors are spatially distributed depending on this regional definition. In the second section, the resource side of the system is explained. It includes the following activities: extracting and importing energy resources, and converting them into other usable forms of fuels. This section is ordered by fuels, thus they are explained fuel-wise. For each fuel, production quantity, reserves and production costs are given first, followed by the process (activity) descriptions. Finally the network representation of the system as in the mathematical model is illustrated. The third section explains the power sector. In the power sector, electricity generation by power plants in each region is explained. First, current generation/consumption amounts, capacity limits and costs, and the modeled technologies are introduced. Electricity transmission system which connects the regional generation systems is explained later. Then, these are brought together as a network illustration of the model. The electricity distribution is not separated from the consumption of electricity. Therefore it is explained in the demand sectors section. The fourth section contains the demand sectors which are organized by sectors under five major titles. In this section, the sectors are described, and their consumption amounts with future trends are discussed. The final section explains a portion of the environmental effect of the energy system, gas emissions. Here, the substances considered in this model and their relationship with energy related activities are explained, and their current levels and historical development are demonstrated.

Turkey is situated between Europe and Asia which makes it a natural, social and economic bridge between the two. Despite recent natural and economic shocks that brought significant fractures, the development trend continues. As of 2003, the gross domestic product (GDP) of the country was around 240 billion $, compounded by and average annual growth of 6% since then. The population is over 70 million which increases, on the average, by 1.3% annually.

Table 3.1 Turkey, 2003 Highlights

Population	70.7 *Million*	
GDP (current prices)	239.8 *Billion $*	
Final energy demand	65.0 *Million toe*	
Oil products	24.6 *Million tons*	(39.3%)
Natural gas	8.5 *Billion* m^3	(12.3%)
Electricity	110 *Billion kWh*	(14.7%)
Coals	23.8 *Million tons*	(18.4%)
Generation capacity	35.6 *GW*	

Turkey has undergone important changes like all developing countries. High domestic migration rates to big cities, unemployment and unfair income distribution are significant. Along with these, the country has been moving from a rural society to an industrial one consistently, which increases the share of industry in the GDP. Knowing that the energy demand follows (in most of the cases) the GDP, it is foreseeable that this economic growth, which is expected to continue in the middle term, will consequently require significant increases in the energy demand. As of 2003 the total energy demand was around 65 million toe (83.8 million toe when total energy supply is considered), which is expected to rise up to 100 million toe (125 million toe) by 2010 and to 170 million toe (220 million toe) by 2020. Table 3.1 presents energy highlights of Turkey as of 2003.

Turkey’s location is of special strategic importance considering the world energy system. It has taken steps to be the energy corridor to Europe and increase its strategic and economic importance. These steps will also play a significant role in solving possible supply security problems. Turkey is also proximate to the richest oil reserves in the Middle East and the Caspian Sea, but unfortunately has a very small reserve of its own. Same situation is valid for natural gas. As Table 3.1 demonstrates these two constitute more than half of the country’s consumption bundle. Therefore dependency on imported fuel is obvious and threatening. The most significant domestic energy resource is lignite. On the other hand, their calorific values are low and impurities are high, which makes them environmentally undesirable. Turkey has also significant renewable resources however the renewable potential of the country is not satisfactorily utilized yet.

A final note on the energy sector will be mentioning the policy makers in Turkey. The Ministry of Energy and Natural Resources (ETKB or MENR[1]) is responsible for assessing the country’s needs for energy and natural resources, determining the necessary policies, preparing plans to reach the policy objectives and providing coordination between governmental and private institutions. Electrical Power Resources Survey and Development Administration (EİE) is responsible for researching water and other energy sources and evaluate their convenience to generate electricity. Other concerns are new energy resources and energy conservation. State Hydraulic Works (DSİ) is responsible for developing,

[1] ETKB is the original Turkish acronym, MENR will be used hereafter.

planning, managing and operating water resources. Turkish Atomic Energy Authority (TAEK) is responsible for determining Turkey's nuclear energy policy bases. Energy Market Regulatory Authority (EPDK or EMRA[1]) is responsible for licensing every private entity that acts in the energy sector, regulating the markets and supervising market operations of the firms. Finally, Petroleum Pipeline Corporation (BOTAŞ) and Turkish Petroleum Corporation (TPAO) are two national corporations which are responsible for operating the oil and natural gas pipelines, and exploring, drilling and producing oil, respectively. After this brief introduction we examine the energy system in detail, beginning with the geographical division assumed for the system.

3.1 Geographical Regions

The distribution of energy resources is not homogenous in the country. For instance all the hard coal is extracted in Zonguldak, and most of the domestic hydraulic resources lie in the eastern part of the country. Such a non-homogenous distribution is also obvious in the demand side. Marmara is the most developed and consuming part of the country whereas the Southeastern Anatolia is the least developed. The distribution of industry sectors is also different among regions. Considering these regional differences we built the model considering geographical information. In the model the country is divided into three regions whose borders follow the province borders. Figure 3.1 illustrates this regional division and Table 3.2 lists the cities belonging to each of the regions.

All resources, power plants and demand sectors were distributed to these regions based on the region specific information obtained from various resources. For instance all the domestic hard coal and natural gas is produced in Region 1, where all domestic oil is produced in Region 3. The only nuclear power plant project is assumed to be in Region 2, Akkuyu (Mersin) or Sinop. The distribution of the resources will be explained under the related resource section.

[1] EPDK is the original Turkish acronym.

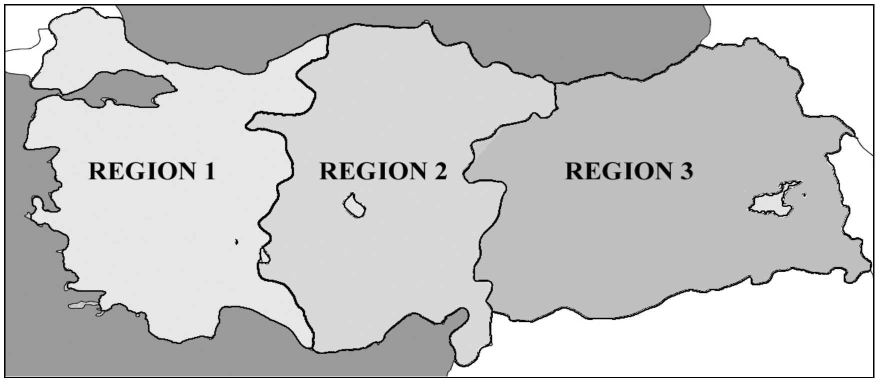


Figure 3.1 Regions of the Country[1]

Similarly the oil refineries and the power plants (aggregated based on fuel) are modeled in different regions. For example the four oil refineries are in Region 1 (İzmit and İzmir), Region 2 (Kırıkkale) and in Region 3 (Batman). The electricity transmission system has both intra-region and inter-region (connecting regions) components. The conversion facilities and the transmission system are explained in the related section: refining in oil resources, power plants and transmission system in power sector.

Finally the demand is divided into the regions. The distribution basis for residential demand is the housing area [40]. For transportation demand, it is number of vehicles [40]. The industry demand is divided between regions based on the manufacturing industry energy statistics [41]. Agricultural energy demand is distributed based on the number of tractors [40] and finally the population [40] is the distribution basis for the non-energy demand for energy sources. The details regarding the regional distribution of the demand and also the fuel vs. electricity division is explained in detail in the demand sectors section.

[1] All maps were drawn by the author.

Table 3.2 Regions and Provinces

Region 1 :	Afyon, Antalya, Aydın, Balıkesir, Bartın, Bilecik, Bolu, Burdur, Bursa, Çanakkale, Denizli, Düzce, Edirne, Eskişehir, Isparta, İstanbul, İzmir, Kırklareli, Kocaeli, Kütahya, Manisa, Muğla, Sakarya, Tekirdağ, Uşak, Yalova, Zonguldak
Region 2 :	Adana, Aksaray, Amasya, Ankara, Çankırı, Çorum, Hatay, Karabük, Karaman, Kastamonu, Kayseri, Kırıkkale, Kırşehir, Konya, Mersin, Nevşehir, Niğde, Ordu, Osmaniye, Samsun, Sinop, Tokat, Yozgat
Region 3 :	Adıyaman, Ağrı, Ardahan, Artvin, Batman, Bayburt, Bingöl, Bitlis, Diyarbakır, Elazığ, Erzincan, Erzurum, Gaziantep, Giresun, Gümüşhane, Hakkari, Iğdır, Kahramanmaraş, Kars, Kilis, Malatya, Mardin, Muş, Rize, Şanlıurfa, Siirt, Şırnak, Sivas, Trabzon, Tunceli, Van

3.2 Resources

The model considers 18 resources which are explained in this section. They are *hard coal* including *coke*, *lignite*, *petroleum coke*, *crude oil* and refined oil products: *gasoline*, *diesel oil*, *fuel oil*, *liquefied petroleum gas* (LPG), *jet fuel* (mostly Kerosene) and *other oil* (mostly Naphtha); *natural gas* including *liquefied natural gas* (LNG) and renewable resources like *wood & biomass*, *geothermal heat* and *solar heat*. Hydraulic, geothermal, wind and nuclear electricity are explained under the power sector. Other fuels like asphaltite and briquette are disregarded as they have an insignificant share in the energy supply.

Hard coal, lignite, crude oil and natural gas, and secondary fuels coke and refined oil products are domestically produced. All of them (except lignite) are also imported together with petroleum coke and LNG. Renewable resources are all domestic. Among the domestic production lignite has the largest share with 46.2 million tons (9.5 million toe) of sellable production in 2003, which constitutes 40% of all domestic production.[1] This is followed by wood & biomass and crude oil production. In the imports bundle crude oil has the largest share. 24.2 million tons of imported crude oil has a share of 44%, which is followed by imported

[1] All resources (hydro wind, etc.) were considered while finding the percentages. The percentages are calculated based on the common energy unit, tons of oil equivalent (toe).

natural gas with 34%. Table 3.3 summarizes the production and import of primary energy resources between 1990 and 2003 [42], [43].

Table 3.3 Primary Energy Resources Production and Import

	Hard coal (M tons)	Lignite (M tons)	Petcoke (M tons)	Crude oil (M tons)	Natural gas (M m3)	Geo-thermal (K toe)	Solar heat (K toe)	Wood & Biomass (M tons)
				Production				
1990	2.7	44.4	-	3.7	212	364	28	25.9
1995	2.2	52.8	-	3.5	182	437	143	25.1
2000	2.3	60.9	-	2.7	639	648	262	22.9
2003	2.1	46.2	-	2.4	561	784	350	20.4
				Import				
1990	5.6	-	0.5	20.1	3,257	-	-	-
1995	5.9	-	0.9	23.5	6,859	-	-	-
2000	13.0	-	1.2	21.7	14,821	-	-	-
2003	16.2	-	1.7	24.2	20,823	-	-	-

3.2.1 Hard Coal

Hard coal is the type of coal which has a gross calorific value above 5700 kcal/kg. (See Appendix A for a list of calorific values for fuels) As a domestic resource, is found only in Zonguldak basin (Region 1). The basin has geological reserves of 1,330 million tons of which around 550 (%41) are proven reserves. 67% of the sellable hard coal can also be coked. The geological structure of the basin does not allow mechanization, so that the extraction is done manually and this labor intensive structure of the extraction process causes the production costs to be very high. Most of the hard coal is extracted by the state-owned Turkish Hardcoal Institution (TTK). The run of mine coal extracted is cleaned in the coal washing facilities. These facilities have a total processing capacity of 12.6 million tons hard coal per year. The production facilities at the basin have sellable coal production capacities of 4.75 million tons/year (approximately 7.8 million tons run of mine production). However, the utilization of this capacity has gradually reduced from 4.5 million tons in 1970 to 1.5 million tons in 2006. In the model, investment cost to increase this capacity was assumed to be $4.5 /ton/year. Table 3.4 shows the hard coal reserves, their coking potential and calorific values; and Table 3.5 shows the capacity, production and costs [43], [44], [45].

Table 3.4 Hard Coal Reserves and Characteristics

	Proven Reserves *(Mtons)*	**Total Reserves** *(Mtons)*	**Coking Potential**	**Calorific Value** *(kcal/kg)*
Kozlu	79,8	168,3	✓	6,740
Üzülmez	141,7	310,0	✓	6,740
Karadon	143,3	419,5	✓	6,710
Armutçuk	12,9	36,6	×	6,725
Amasra	173,1	409,7	×	5,840

Table 3.5 Hard Coal Production Capacity, Production and Costs

Capacity *(Mtons/yr)*	**Production** *(Mtons)*	**Import** *(Mtons)*	**Production Cost** *($/ton)*	**Washing Cost** *($/ton)*	**Coking Cost** *($/ton)*	**Import Cost H.Coal** *($/ton)*	**Import Cost Coke** *($/ton)*
4.75	2.059	16.166	128.27	4.20	14.71	40.75	58.68

The production cost of domestic hard coal is very high compared to the import cost of hard coal. As a result the government subsidizes the domestic coal production. The selling price of the domestic coal was about $66 per ton in 2003. Note that the production costs are in terms of $/tons of output and the import costs (all) include cost insurance and freight (CIF). The costs here are used as model parameters, with projections of international prices through the planning horizon. See Appendix D for hard coal related costs and projections.

Finally let us discuss *coke,* which is a secondary fuel obtained from hard coal as a result of the process known as coking. Coking is a process where hard coal is put in an oven with a temperature around 1000°C and the volatile substances in it are vaporized. The resulting porous coal is called coke and it is most commonly used by the iron-steel industry in blast furnaces. The thermal efficiency of this process is calculated as 76.84% based on the 2003 Energy Balance. In 2003, 4.032 million tons hard coal (2.984 M toe) is coked this process resulted in 2.878 million tons coke (2.014 M toe). In the model as we assume a standard calorific content, 6500 kcal/kg, for hard coal, we calculate the thermal efficiency coking process to be 76.8%.

After the introduction to the hard coal sector, it would be better to continue with the model illustration of this sector. But, before giving the illustration it is better to develop a guideline for understanding the illustration. The illustration (network) in Figure 1 is a component of the Reference Energy System (RES) we assume for the Turkish energy system. A RES is a network representation of the energy related technological activities from supply end of the system to the demand end. These activities are extraction, cleaning, conversion, gasification, transportation, power generation, power transmission and final consumption through a utilizing device.

Every node in the network represents a located fuel. For instance, Node 3 is the hard coal in the mine; Node 4 is the extracted hard coal at the mine mouth and Node 5 is the cleaned sellable hard coal at the finished goods stock of the cleaning facility – note that they are all in Region 1 for this case. The nodes follow the material flow and represent a certain fuel at a certain location. The definition of an arc is then straightforward. An arc is an activity that converts a fuel to another form or simply transports it. Returning to the previous example, Arc 3 is extraction of the hard coal and Arc 4 is the washing of the hard coal. As every arc represents an activity, each one of them has two associated fundamental parameters: activity cost and thermal efficiency. The parameters will be explained later in the model section. The numbers on the nodes and the arcs are the same as the ones in the model indices I and J respectively, so a direct correspondence between the model network and the illustration exists. Diamond P represents the power sector, the Square D represents demand sector and the dotted and dashed lines represent transportation to power plants and demand sectors respectively. Since the entire network is large and it is inconvenient to show all of it, the network is divided and presented as individual sectors. However, in each sector network, the final nodes of the corresponding previous sector network are presented in order to avoid confusion. For example, Node 5 is a final node of the hard coal sector network, so it is found in the power sector network as well, to show the origin of the coal burned in the power plant. Figure 3.2 represents the hard coal sector of the energy network as it is embedded in our model.

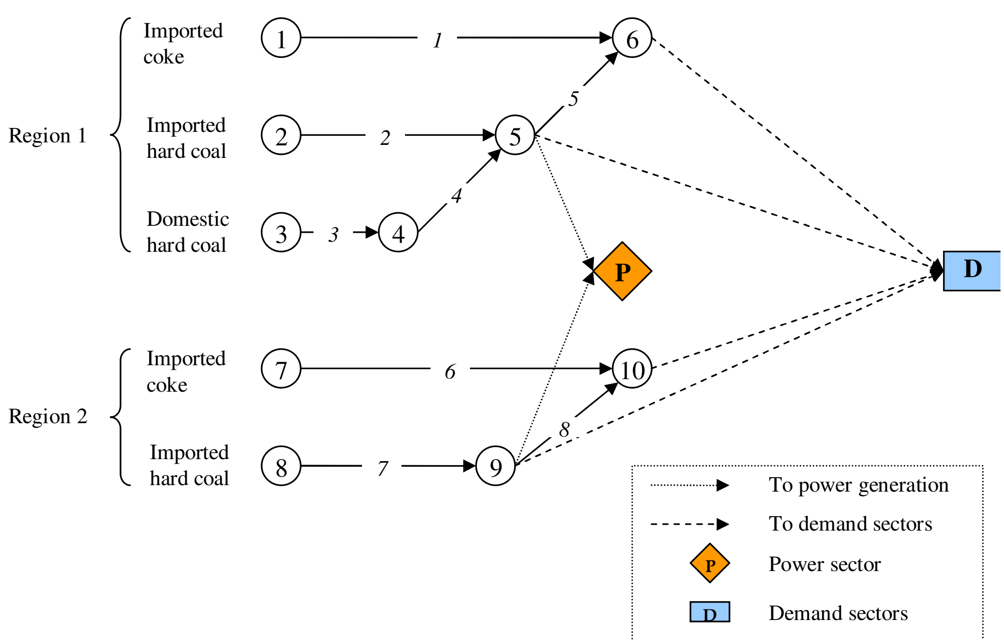


Figure 3.2 Hard Coal Extraction, Importing and Processing[1]

Since all the domestic hard coal is extracted in Region 1, the only extraction activity is defined there. Importing is defined only for Regions 1 and 2 as the coal is imported only through the ports in these regions. The domestic hard coal is first

[1] Every network illustration in the main body of the report is prepared by R. Düzgün.

extracted (3) and then cleaned (4). Imported hard coal is purchased and transported to national ports (2, 7). Both domestic and imported hard coal then follows one of the three routes; it is transported to power plants for electricity generation, transported to the demand sectors for final use as hard coal or coked in coking plants (5, 8) mainly to satisfy the demands of the iron and steel production sector. The imported coke in both regions is first purchased and transported to national ports (1, 6) and then together with domestically processed coke they are transported to the demand sectors.

3.2.2 Lignite

Lignite is found and extracted vastly in all regions of the country. It is the lowest rank of coal and it may also be referred as brown coal. The largest reserve is in Afşin-Elbistan. However, as the calorific value is low (1100 kcal/kg), it is used by power plants rather than being marketed. Other important reserves are Soma, Tunçbilek, Seyitömer, Beypazarı and Kangal. Turkey’s lignite reserves are about 8.4 billion tones of which %90 are proven reserves. Figure 3.3 presents a map of Turkey showing the hard coal, lignite, oil and natural gas deposits.

The mining process is mechanized as the most of them opencast mines. The production capacity in 2004 was about 78 million tons per year. For lignite, the capacity expansion cost for the mines was assumed as $0.6 /ton/year. The under utilization issue is true for lignite sector, too. In 2003 46.2 million tons of lignite is produced, which was 65 million tons in 1999. As mentioned earlier, most of the lignite reserves have low calorific values; and those with lower calorific values are burned by the thermal power plants located around the deposits. Marketed lignite is washed by the coal washing facilities before transportation to demand sectors.

The lignite mines and washing facilities in Turkey are mostly operated by the state-owned firm, Turkey Coal Enterprises (TKİ). These facilities have a capacity of 31 millions tons per year. Some of the lignite mines are operated by Energy Production Corporation (EÜAŞ), which is also owned by the state. EÜAŞ extract lignite to supply its thermal power plants. Lignite is only produced domestically, thus no lignite has been imported.

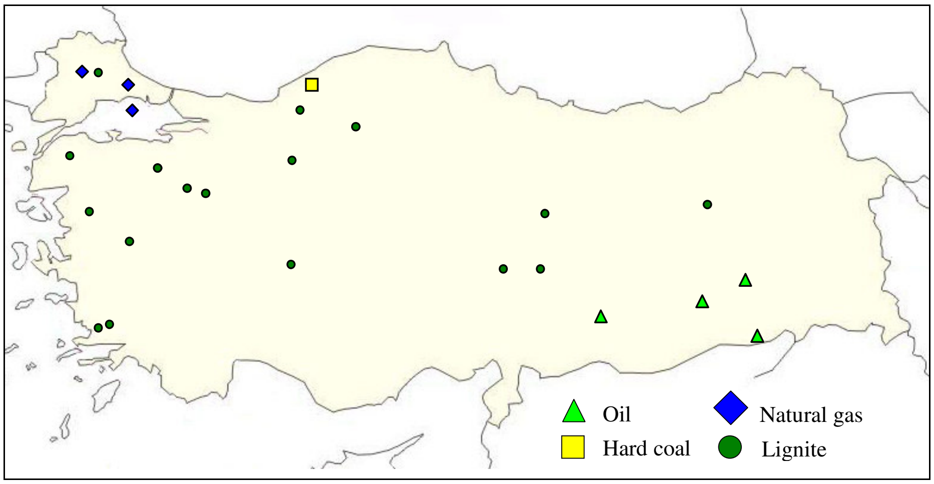


Figure 3.3 Turkey, Natural Energy Resources

Table 3.6 shows the major lignite reserves, their calorific values and the regional distribution of Turkey's lignite reserves [46]. Note that the regional calorific values are the ones that are assumed in the model

As lignite is extracted in opencast mines, the production cost per ton is much less compared to hard coal. This cost varies between regions. The mines in Region 1 have an average production cost around \$15.52 per ton. This cost is \$24.94 and \$8.88 for Region 2 and Region 3, respectively. The cost of washing lignite is assumed to be \$5.93 per ton in 2003. These production quantities, capacities and costs related to the lignite sector are summarized in Table 3.7 [43].

Table 3.6 Lignite Reserves and Characteristics

	Proven Reserves (M ton)	Total Reserves (M ton)	Lower Calorific Value (M ton)
Adana-Tufanbeyli	211.4	271.2	1350
Ankara-Beypazarı	406.0	504.0	2567
İstanbul-Silivri	114.2	190.2	1908
Konya-Beyşehir	159.0	239.0	1176
Konya-Ilgın	189.2	189.9	2110
Kütahya-Seyitömer	167.1	167.1	1900
Kütahya-Tunçbilek	304.7	304.7	2250
Manisa-Soma	472.3	572.2	2555
K.Maraş-Elbistan	3,357.3	3,357.3	1050
Muğla-Milas	296.4	296.4	1927
Muğla-Yatağan	324.6	326.0	2538
Sivas-Kangal	202.6	202.6	1315
Tekirdağ-Saray	23.6	129.2	1980
Other	4,780.4	1,470.6	
		By Regions	
Region 1	2,759	2,110	2500
Region 2	1,661	1,207	2500
Region 3	3,799	3,742	1100

Table 3.7 Lignite Production Capacity, Production and Costs

	Capacity (Mtons/yr)	Production (Mtons)	Production Cost ($/ton)	Washing Cost ($/ton)
TKİ				
Western Anatolia	45.8	25.278	15.52	5.93
Central Anatolia	0.5	0.319	15.52	
Kangal	3.8	3.797	7.92	
Afşin-Elbistan	17	7.379	9.38	
Çayırhan	5	4.47	24.93	
Other	7.347	4.817	24.93	
		By Regions		
Region 1	50.972	29.35	15.52	5.93
Region 2	6.02	5.402	24.94	5.93
Region 3	21.955	11.306	8.88	5.93

Below is the network for the lignite sector. Lignite is extracted first (15, 16, 17) in a region. After extraction, it is either transported to the power plants which are situated close to the basin or further processed and cleaned to make it sellable (18, 19, 20) and then transported to the demand sectors for final use. The explained structure can be seen in Figure 3.4.

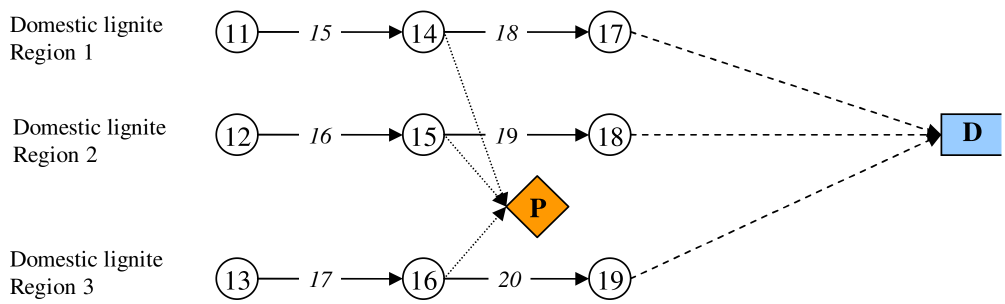


Figure 3.4 Lignite Extraction and Processing

3.2.3 Petroleum Coke

Petroleum coke (pet-coke) is a carbon rich residue of the oil cracking operation. It has a calorific value of 7700 kcal/kg. It is mainly consumed by the cement industry. It's preferred because of its high heating capacity and comparatively low price. It is not domestically produced. In 2003 1.67 million tons of petroleum coke (1.286 M toe) was imported. Average price (CIF) of petroleum coke was $37.78 per ton in 2003.

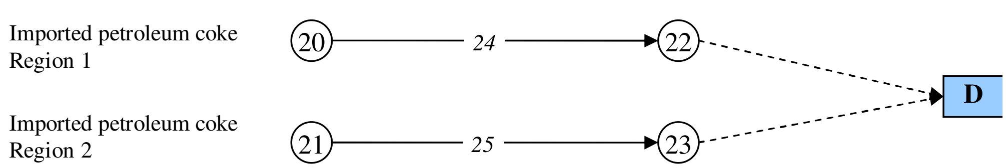


Figure 3.5 Petroleum Coke Importing

The network for petroleum coke is quite simple. It is purchased and transported to the national ports (24, 25) in Region 1 and Region 2, respectively. After that, it is transported to demand sectors for final use. The explained structure can be seen in Figure 3.5.

3.2.4 Crude Oil and Oil Products

Despite the high share of oil in its energy consumption bundle, Turkey has very small reserves of oil (42.76 M tons). Considering the production level in 2003 which is 2.3 million tons, the known reserves will be depleted in 19 years. Almost all of this domestic oil is produced in the Southeastern Anatolia. Domestic crude oil is refined mainly in the Batman Refinery which has a capacity of 1.1 million tons. Rest of the domestic oil is transported through the Batman-Ceyhan oil pipeline whose capacity is 3.5 million tons per year, and then to other refineries.

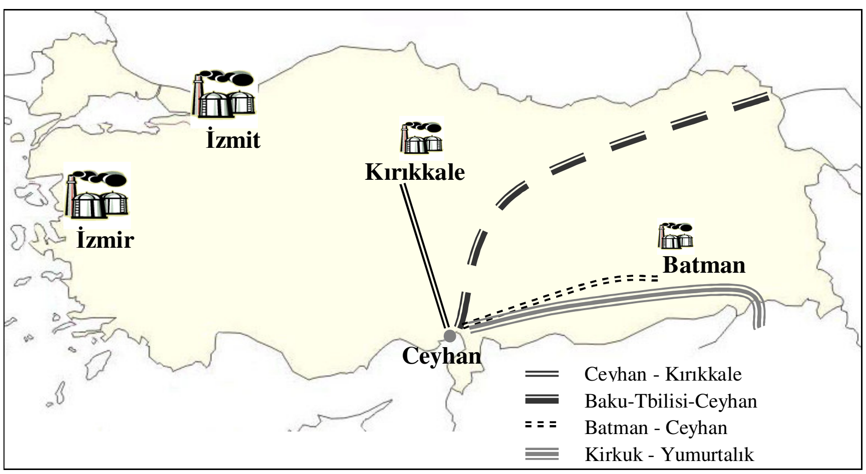


Figure 3.6 Turkey, Oil Refineries and Pipelines

In addition to the domestic production, Turkey exports crude oil. In 2003 Turkey has imported 24.1 million tons of crude oil. This figure constitutes 38.8% of the total energy imports. When oil products import is counted as oil import, this share increases to 52%. Domestic oil and the imported crude oil are transported to the refineries in İzmit, İzmir and Kırıkkale. Between Ceyhan and Kırıkkale there is an oil pipeline with a capacity of 5 million tons. Beyond these Turkey has two international pipelines. Baku-Tbilisi-Ceyhan pipeline carries the oil from Caspian Sea to Ceyhan and has a capacity of 25 million tons per year. The last oil pipeline is between Kirkuk and Ceyhan. It is idle for a long time but it had a capacity of 70.9 million tons per year. Figure 3.6 shows the oil pipelines and refineries in Turkey.

Insignificant oil reserves in Marmara are ignored, so crude oil is extracted only in the Southeastern Anatolia (Region 3). After it is extracted (26) it is transported to one of the four oil refineries in İzmit (27), İzmir (28) which are in Region 1; and to Kırıkkale (29) and Batman (30) which are in regions 2 and 3, respectively. Imported crude oil is similarly purchased and transported to the refinery ports in İzmit (31), İzmir (32) and from Ceyhan Port with pipeline to Kırıkkale (33) and Batman (34). Figure 3.7 presents the network explained above. The capacity of domestic production, production and crude oil import quantities, and production and import costs are summarized in Table 3.8. Then quantities and costs for each refinery for domestic and imported crude oil are tabulated in Table 3.9 [43].

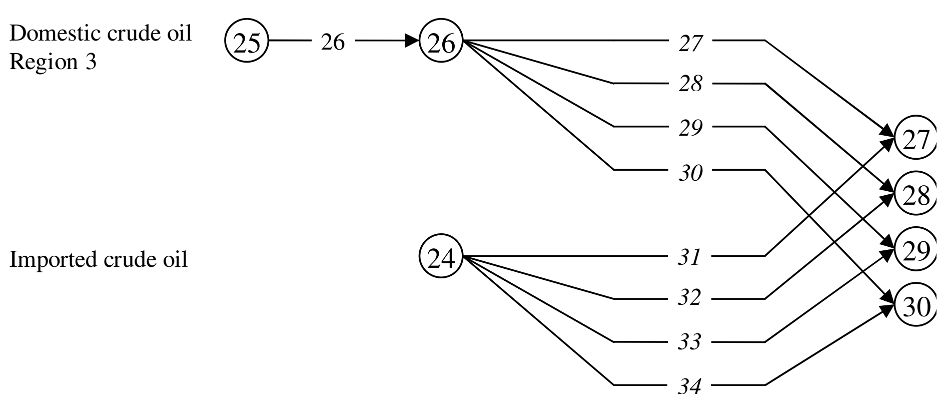


Figure 3.7 Crude Oil Extraction, Import and Transportation

Table 3.8 Crude Oil Production and Import, Quantities and Costs

	Capacity *(M tons/yr)*	Quantity *(M tons)*	Cost *($/barrel)*	Cost *($/ton)*
Domestic	2.375	2.327	4.51	32.92
Imported	-	24.21	27.05	197.47

Table 3.9 Crude Oil Import and Transportation to Refineries

	Domestic		Import	
	Quantity *(M tons)*	**Cost** *($/ton)*	**Quantity** *(M tons)*	**Cost** *($/ton)*
İzmit	0.293	5.56	9.359	5.60
İzmir	0.072	3.72	9.633	3.99
Kırıkkale	0.691	7.62	2.969	8.51
Batman	0.848	-	0.075	-
Ataş	0.424	-	2.174	-

Note that there is another refinery named Ataş. It is in Mersin, located in Region 2. However the refinery is shut down in 2004, so it is not included in our model. The costs for imports given in Table 3.7 are not considered in the model as the import costs were taken as CIF. However pipeline transportation cost ($2.92/ton) is added to the projected crude oil CIF costs for Kırıkkale. As oil is not consumed in the crude form, it is refined. When crude oil is refined various refined oil products are produced which are used as fuel or feedstock by the industry. In the model gasoline, diesel oil, fuel oil, jet fuel (kerosene), LPG and other oil (mostly naphtha) are considered as refined oil products. Figure 3.8 shows how the refining processes are modeled as a network. After that, quantities, costs and some special information on refineries will be discussed. The crude oil transported to the refineries is refined and as a result gasoline (35, 41, 47, 53), diesel oil (36, 42, 48, 54), fuel oil (37, 43, 49, 55), LPG (38, 44, 50, 56), jet fuel (39, 45, 51, 57) and other oil (mostly naphtha) (40, 46, 52, 58) are produced. Although the current refining system is organized plant wise the refined products are organized region wise by aggregating the output of İzmit and İzmir refineries for Region 1.

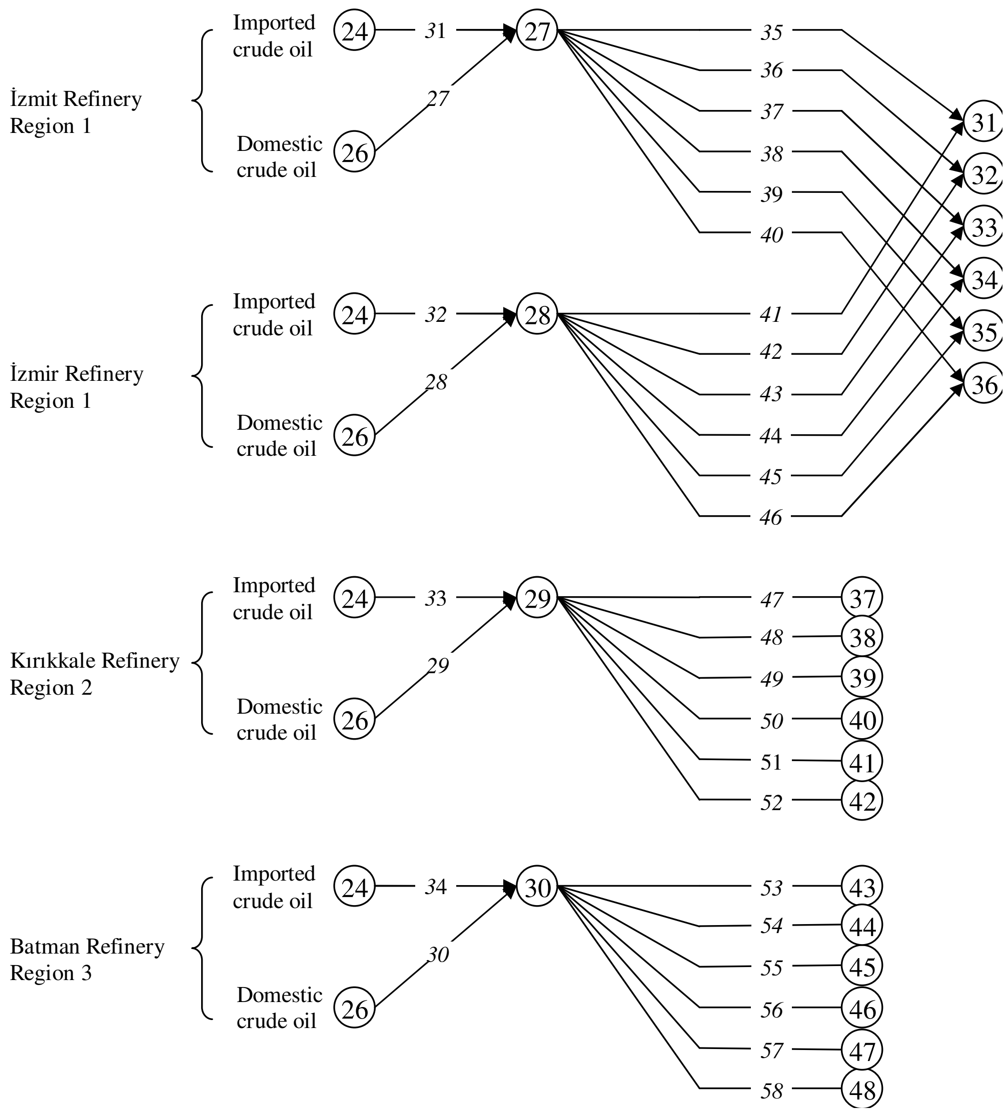


Figure 3.8 Crude Oil Transportation and Refining

When crude oil is processed, these oil products are produced in different proportions by different refineries. This is modeled as a *refinery maximum percentage* defined for each refinery-fuel pair. This is found by comparing the last seven years' output (in common unit, toe) percentages for each refinery. Table 3.10 shows the processing capacities, quantity of crude oil processed, quantity of refined products produced, refining costs and the found refinery maximums (in parentheses) in 2003. Finally, Investment cost for a refinery is assumed as \$10,200 /barrel/day which is equal to (\$204 /ton/year).

Table 3.10 Refinery Outputs, Refining Costs and Maximum Percentages

	İzmit	**İzmir**	**Kırıkkale**	**Batman**
Capacity *(M ton/yr)*	11.5	10	5	1.1
Crude oil *(M ton)*	9.651	9.703	3.659	0.923
Gasoline	1.394	1.583	0.454	0.029
(M ton)	(19.2%)	(18.43%)	(21.2%)	(6.58%)
Diesel oil	2.693	3.178	1.219	0.129
(M ton)	(30.32%)	(35.8%)	(37.44%)	(18.11%)
Fuel oil	2.481	2.112	0.782	0..414
(M ton)	(27.85%)	(27.9%)	(27.75%)	(47.17%)
LPG	0.263	0.314	0.113	0.003
(M ton)	(4.07%)	(3.92%)	(4.1%)	(0.89%)
Jet fuel	0.786	0.727	0.168	0.004
(M ton)	(9.77%)	(9.11)	(5.99%)	(0.76%)
Other oil	1.566	1.014	0.642	0.293
(M ton)	(21.08%)	(24.51%)	(19.42%)	(51.11%)
		Refining Costs *(\$/toe)*		
Gasoline	78.29	56.92	69.72	113.04
Diesel oil	44.49	27.72	33.26	63.81
Fuel oil	-55.93	-72.92	-60.76	-41.09
LPG	104.95	77.81	89.54	155.93
Jet fuel	50.99	22.8	40.16	146.93
Other oil	-3.95	-22.77	-46.54	-9.72

The oil products can also be obtained by importing. For instance Turkey imports 80% of the LPG it consumes, imports diesel that conforms to the European standards and imports other oil as solvents or other chemical non-energy products. Oil product import is illustrated in Figure 3.9. Arcs 59 to 76 denote an importing activity for a fuel type to a region. These imported oil products combine with the

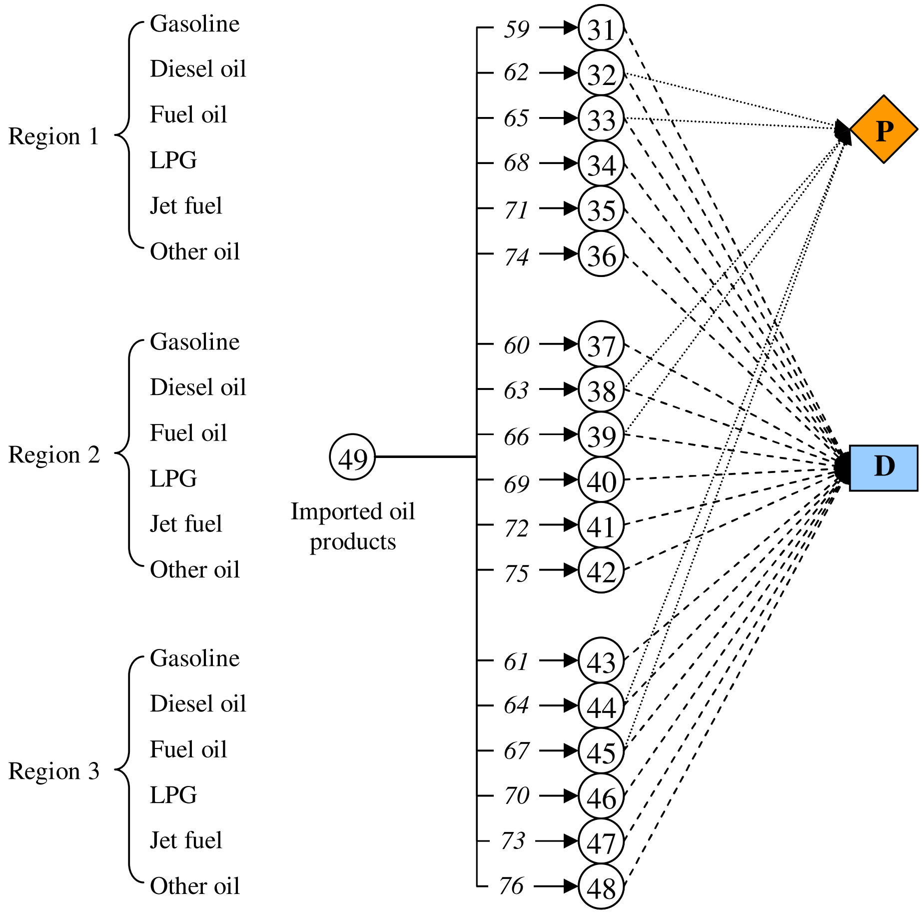


Figure 3.9 Oil Products Import

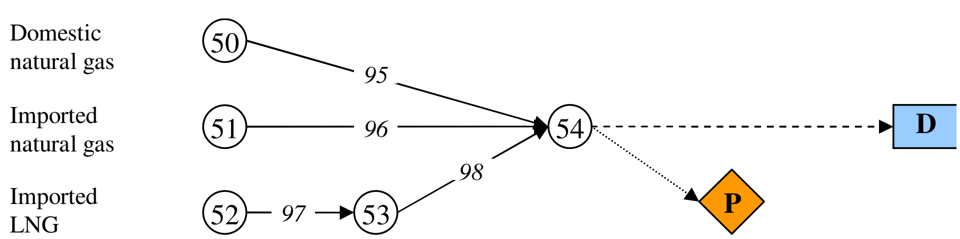


Figure 3.10 Natural Gas System

refined ones by region. Note that each of the nodes 31 to 48 denotes an oil product in a given region and the order is the same in all associated figures: gasoline, diesel oil, fuel oil, LPG, jet fuel and other oil. The path followed by oil products which are combined after refining and importing. Two of these oil products, diesel oil and fuel oil, are also used for electricity generation. Thus after the refining or importing they are either transported to the demand sectors or the power plants. The remaining oil product types are transported to the demand sectors and are either used as fuel or feedstock.

Table 3.11 Refined Oil Product Import, Quantities and Costs

	Import Quantity *(M ton)*	**Import Cost (CIF)** *($/ton)*
Gasoline	0.446	272.74
Diesel oil	2.714	266.35
Fuel oil	0.739	172.60
LPG	3.087	277.01
Jet fuel	0.007	281.27
Other oil	1.183	225.87

The imported quantities and import prices of the oil products imported are listed in Table 3.11. See Appendix D for these prices, oil prices and projections.

3.2.5 Natural Gas

Like oil, Turkey's gas reserves are small. In 2003, remaining gas reserves was 7.95 billion m^3. Considering the current production capacity of 561 million m3, the resources will be emptied in 15 years. Consequently, Turkey imports 97% of the natural gas it consumes. The gas is imported in two ways. The first way is through pressurized gas pipelines. Russia and Iran are the major suppliers in this segment. The other way is by sea, in liquefied natural gas (LNG) vessels. This gas is then regasified in LNG gasification plants and turned into usable natural gas.

Nigeria and Algeria are the two suppliers of LNG to Turkey. The supplied natural is gas is transmitted countrywide through steel transmission pipelines. Finally they are distributed to the end users through steel and polyethylene pipelines. Figure 3.11 shows the international pipelines, gasification plants and major transmission lines in Turkey.

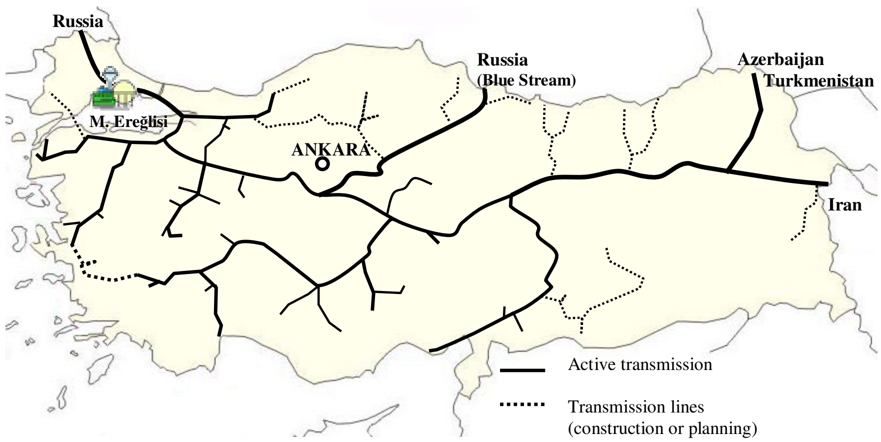


Figure 3.11 Turkey, Natural Gas Infrastructure

In the above map, the lines that Turkey uses were included. Besides Turkey would like to be the energy corridor to Europe and transmit Russian, Turkmen and Persian gas to the western markets. These cross border pipelines are planned to be built between Turkey and Greece, Turkey to Austria and the recent agreement with Iran are current projects. Another important fact about natural gas is that its price is not determined by the market. The largest supplier, Russia, determines the price and the contract. Recent gas crises in Europe and Turkey reveal that the supply security and supplier diversification are important topics in natural gas sector. This importance doubles as households convert to natural gas for residential heating and natural gas becomes dominant in the electricity generation setor. Table 3.12 summarizes the capacities, quantities and costs related to the natural gas sector in 2003.

Table 3.12 Capacity, Quantity and Cost Data for Natural Gas

	Capacity *(M m^3)*	Quantity *(M m3)*	Cost *($/1000 m3)*
Domestic Production	561	561	7.64
Pipeline Import	-	15,921	142.29
LNG Import	-	4,903	146.38
LNG Regasification	6,500	-	15.51
Transmission	-	-	16.32

The natural gas sector was illustrated in Figure 3.10. The operations on the network may be explained as follows. Domestic production (95) of natural gas is carried out in the Marmara region (Region 1). Most of the natural gas consumed by the country is obtained through three large natural gas pipelines; this is embedded in the model as natural gas importing (96). The remaining natural gas is imported as LNG (97) and is regasified (98) in the regasification facilities in Region 1. The natural gas system, unlike the others, is not defined region-wise but is accepted to be a single countrywide entity after being combined. This combined natural gas is then either transported to the power system to be used in power generation or transported to the demand sectors for final use.

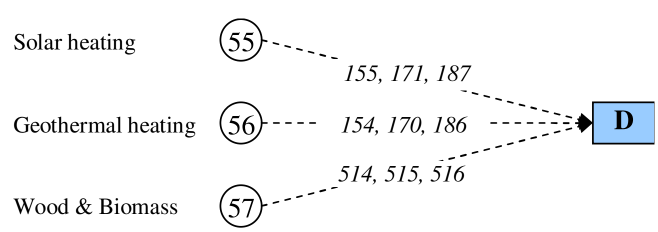
3.2.6 Renewable Resources

In the resources section, solar heat, geothermal heat and wood &biomass are considered. Solar heat is utilized by solar panels and is used mostly for water heating. This is quite common, especially in the southern regions of the country. Turkey on the average sees sunshine 2640 hour per year. This equals to 1311 kilowatt-hours per square meter, annually. In Southeastern Anatolia, Mediterranean and Aegean regions, these go up to 2993 hours per day and 1460 kilowatt-hours per square meter per year. Turkey has used 350 thousand toe of solar energy. And this is continuously increasing.

Another renewable resource is geothermal heat. Turkey has significant geothermal resources, but has not gone far enough in utilizing them. Geothermal heat is used mostly for thermal resorts, district heating and heating the greenhouses. Most of these applications are in the Aegean region (Region 1) as the geothermal potential of the country is mainly located on the faults in that region. Turkey's geothermal heating potential is about 31500 megawatts-thermal, which is capable of heating 5 million houses. Current capacity, on the other hand is around 2500 megawatts-thermal, but utilized potion is 784 megawatts-thermal as of 2003.

Final renewable resource mentioned in this section is wood &biomass. From another point of view these resources are not renewable, especially the wood. But it is commonly listed among renewable resources as with careful planning, woodcutting may be performed without depleting the forests. In 2003, 20.43 million tons of wood (14.99) and biomass (5.44) are consumed. This is equals 5.75 million toe. It's hard to determine the capacities for wood &biomass and solar. So for convenience 2003 consumption was assumed as the current capacity for using these resources. As the renewable resources are assumed (exactly true for geothermal and solar heating, mostly true for wood &biomass) to be consumed in the regions where they originate, the network is considerably simple. Renewable resources are directly consumed by the demand sectors and this consumption is shown by, solar heat (155, 171, 187), geothermal heat (154, 170,186) and wood & biomass (514, 515, 516). Figure 3.12 shows the renewables network.

Figure 3.12 Renewables Network



3.3 Power System

In the previous section some of the resources were explained such that they were used for power generation and their transportation to power plants were shown by dotted lines ending at a diamond with the letter "P" in it. Here we explain the power system that was previously denoted with that symbol. We will first explain the components of the generation system, current limits, quantities related to consumption and generation, and costs. After that, the model representation of the generation system will be discussed. Finally the transmission system is explained in the same way as the generation system. Before continuing further lets overview a summary the power sector figures. Table 3.13 and 3.14 present the development of power demand and country infrastructure to supply that.

Table 3.13 Development of Power Sector

Years	Installed Capacity *(GW)*	Generation *(TWh)*	Demand *(TWh)*	Peak Load *(GW)*	Transmission Lines *(1000 km)*	Transformers *(GVA)*
1980	5.12	23.28	20.40	4.02	22.16	12.67
1985	9.12	34.22	29.71	5.74	28.10	19.33
1990	16.32	57.54	46.82	9.06	35.18	28.77
1995	20.95	86.25	67.39	13.88	40.21	37.82
2000	27.26	124.92	98.30	19.41	43.67	58.53
2003	35.59	140.58	111.77	21.66	46.19	67.08

Table 3.14 Development of Installed Capacity

Years	Hard coal	Lignite	Natural gas	Fuel oil	Diesel oil	Hydro electric	Geo thermal	Wind	Other
									unit: MW
1980	323	1,047	0	885	536	2,131	0	0	12
1985	220	2,864	100	1,101	627	3,875	18	0	0
1990	332	4,874	2,210	1,202	546	6,764	18	0	0
1995	326	6,048	2,884	1,149	204	9,863	18	0	14
2000	480	6,509	4,905	1,261	230	11,175	18	19	119
2003	1,800	6,439	8,862	2,331	236	12,579	15	19	194

It is clear from the above figures that the structure of the power sector has changed. Electricity demand has doubled every decade. Installed capacity and transmission investments followed the demand increase. Natural gas has become important as capacity of gas fired plants nearly doubled between 1995 and 2000. Such a doubling occurred just in three years between 2000 and 2003. Investment in lignite plants has stopped. Hard coal power plants experienced such a stop until the addition of a large import hard coal plant in 2003. Utilization of hydraulic resources has constantly grown, but still has way to go, considering the 35 GW potential or Turkish rivers. Geothermal plants, despite the potential, have not been developed. Wind power is newly introduced and it is expected to grow I the coming years.

The power system consists of two parts: generation and transmission. The distribution of electric power is represented in the demand sectors subsection as it is not separated from consumption.

3.3.1 Power Generation

The generation sector consists of the power plants. In the model we classified the power plants by region and then aggregated them by fuel. The considered power plant types were hard coal, lignite, fuel oil, diesel oil, natural gas, hydroelectric, geothermal, wind and nuclear power plants. As of 2003 Turkey has an installed capacity of 35.59 gigawatts (Currently 38.82). See Table 3.12 for the composition of installed generation capacity. When we classify these plants first by region, then by fuel in each region, we obtain the Table 3.15, which summarizes the current capacities of the generation system components. Note that there are two types of hydroelectric plants are defined. The first one refers to larger plants with dam, while the other represents the river plants. This differentiation is essential for the modeling of large power plants as projects. In the model, plants with two fuels were ignored as their contribution is small, and are counted under lignite if they are *lignite+liquid fuel* type; and under fuel oil if they are *LPG* or *naphtha* plants

Table 3.15 Power Plants by Region and Type

	Regions			
Plant Types	**1**	**2**	**3**	***Type Total***
				unit: MW
Hard coal	480.0	1,320.0	0.0	***1,800.0***
Lignite	4,094.5	978.5	1,831.0	***6,904.0***
Fuel oil	1,456.4	476.6	569.1	***2,502.1***
Diesel oil	189.0	2.4	44.2	***235.5***
Natural gas	11,148.4	356.8	0.0	***11,505.2***
Wind	17.4	0.0	0.0	***17.4***
Geothermal	15.0	0.0	0.0	***15.0***
Hydro – Dam	1,200.9	2,949.9	7,732.9	***11,883.6***
Hydro – River	183.9	281.4	229.8	***695.2***
Region Total	***18,785.5***	***6,365.5***	***10,407.0***	

Each of these power plants has distinct properties. Among these properties, efficiency, plant factor, generation cost and investment cost are considered in our model. No other technological or economic property is considered. Table 3.16 below presents the specific properties of the power plants. See Appendix D for these parameters. The last five plant types have efficiency of 1 as the resources for them are already defined in power units. The investment cost is not mentioned here, it will be explained at the end of the power generation section.

Table 3.16 Power Plant Properties

Plant Type	**Efficiency** *(%)*	**Plant Factor** *(%)*	**Generation Cost** *($/MWh)*
Hard coal	40.7	75	8.36
Lignite	40.2	75	13.26
Fuel oil	37.7	75	2.26
Diesel oil	33.9	75	6.78
Natural gas	49.4	80	1.43
Wind	1	40	4.15
Geothermal	1	70	22.57
Hydro – Dam	1	40	1.13
Hydro – River	1	50	0.90
Nuclear	1	80	13.20

We did not include certain resources previously as they were specific to power sector. These resources are hydroelectricity, geothermal electricity, wind energy and nuclear power.

3.3.1.1 Hydroelectricity

Turkey has a considerable hydroelectric power potential of 35.5 giga-watts. As of 2003 Turkey utilizes 35.4% of this potential. This potential is not equally distributed among the regions. The long rivers of Eastern Anatolia possess most of this potential. Below is Figure 3.13 which shows the major river basins, which is followed by Table 3.17 which presents the hydraulic potential in these basins [42].

Figure 3.13 Turkey, River Basins

In the model hydroelectric plants whose capacities were larger than 200 mega-watts were modeled as projects. There were 20 plants of this sort. These plants and their investment costs are given in Table 3.18 [47]. The generation costs for these hydroelectric plants were taken as the same as previously presented value. This situation is valid for all of the power plants.

Table 3.17 River Basins and Hydroelectric Potential

No	Basin Name	Potential *(MW)*	No	Basin Name	Potential *(MW)*
1	Meriç	23.90	**13**	Western Black Sea	507.35
2	Marmara	4.30	**14**	Yeşilırmak	1,270.84
3	Susurluk	373.26	**15**	Kızılırmak	2,060.51
4	Northern Aegean	22.00	**16**	Central Anatolian	42.48
5	Gediz	123.00	**17**	Eastern Mediterranean	1,632.12
6	Küçük Menderes	48.00	**18**	Seyhan	2,048.29
7	Büyük Menderes	278.80	**19**	Asi	53.57
8	Western Mediterranean	596.79	**20**	Ceyhan	1,663.20
9	Antalya	1,432.12	**21**	Fırat	9,672.93
10	Burdur Lake	-	**22**	Eastern Black Sea	3,462.55
11	Afyon	-	**23**	Çoruh	3,178.90
12	Sakarya	1,177.54	**24**	Aras	834.92
		Regions			
Region 1	4,079.71	**Region 2**	9,278.36	**Region 3**	22,181.24

Table 3.18 Hydroelectric Plant Projects

	Project No	Capacity *(MW)*	Investment Cost *($/KW)*	Plant Factor *(%)*
Region 1				
Güresöğüt	12	279	763.4	0.13
Kargı (Sakarya)	19	214.2	1,221.9	0.15
Region 2				
Boyabat - Kepez	3	513	1,306.5	0.33
Kayraktepe	11	290	971	0.30
Göktaş	13	270	1,361.8	0.49
Yedigöze	14	250	971	0.44
Region 3				
Ilısu	1	1,200	873.7	0.36
Yusufeli	2	540	1,237.5	0.36
Doğanlı	4	461.6	802.1	0.33
Uzungöl Of Solaklı	5	380	778.7	0.30
Çetin	6	350	1,010.9	0.40
Artvin	7	332	763.4	0.35
Beyhanı	8	300	1,944.5	0.55
Kandil En. Grubu	9	294.2	1,097	0.43
Kaleköy	10	293	1,610.7	0.50
Çukurca	15	244.9	1,336.4	0.37
Cizre	16	240	1,221.9	0.57
Arkun	17	222	1,764.3	0.41
Alkumru	18	222	1,224.1	0.42
Hakkari	20	208	1,378.6	0.34

3.3.1.2 Geothermal Electricity

We have previously mentioned geothermal heating and its uses and limits. Geothermal electricity originates from the same source. The geothermal resources may be classified according to their temperatures. Temperatures lower than 70° C are called low temperatures sites and are used for heating. Those with a temperature between 70° C - 150° C are medium temperature sites and may be utilized for power generation, but the main use is, again, heating. Those with a temperature higher than 150° C are named high temperature sites and are mainly used for electricity generation; with integrated systems they may serve heating need as well. Most of the geothermal electricity potential of Turkey lies on the long faults in the Aegean Region (Region 1). According to the geothermal inventory determined by MTA, 86.4% of the country potential is in Region 1. For instance the Germencik site in Aydın, is the largest known high temperature site with a potential of 150 MW-electric. Although the operating costs are larger than other plant types, cost of generation is cheap, between 0.01 – 0.03 \$/kWh, as no fuel costs exist. The investment costs are larger compared to other plant types, \$2500 per kW for moderate to large plants and \$3000 - \$5000 per kW for small (< 1 MW) plants. The known geothermal sites are enough to build 430 MW-electric generation capacity, with new exploration this amount is expected to rise up to 1250 MW-electric by 2025.

3.3.1.3 Wind Energy

Turkey has an economic wind energy potential of 10,000 MW. This potential is mainly accumulated in the Marmara region, the Aegean coast (Region 1) and the Eastern Mediterranean coast (Region 2). A wind plant costs \$1250 per mega-watt. Currently, projects with a total capacity of 1269 MW have been licensed by EMRA. Figure 3.14 shows the geothermal plants and wind farms that are in use or licensed by EMRA and under construction as of 2007 [48].

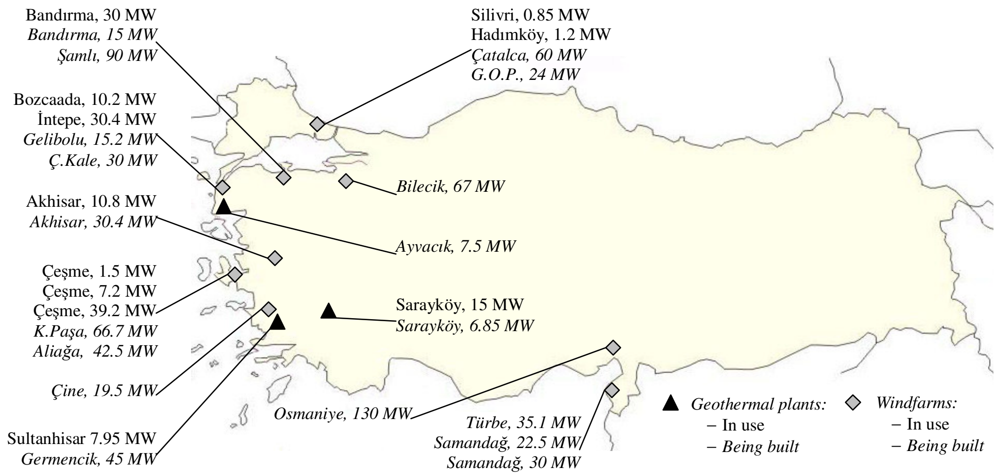


Figure 3.14 Turkey, Windfarms and Geothermal Plants 2007

3.3.1.4 Nuclear Energy

Turkey attempted to build a nuclear plants several times in the past, but has not yet succeeded in adding nuclear energy to its generation capacity. Nuclear energy research is limited to a small scale research reactor built in 1962. Even in BÜTEM (Kavrakoğlu et al. 1977) a possible nuclear plant in Akkuyu, Mersin was modeled. This debate has continued more than 30 years now. In our model, we put a nuclear plant project in Region 2 (Akkuyu or Sinop), which is 1500 MW in capacity and costs $1750 per MW.

Figure 3.15 below represents the electricity generation network. The network is organized by regions. In each region the plants of a fuel type are aggregated and their activity is represented by a single arc. The resources on the left show the fuel and the origin of that fuel, so they represent the dotted arcs in the resources section. The node at the end of each regional generation network (87, 88, 89) represents the beginning of the transmission system for that region.

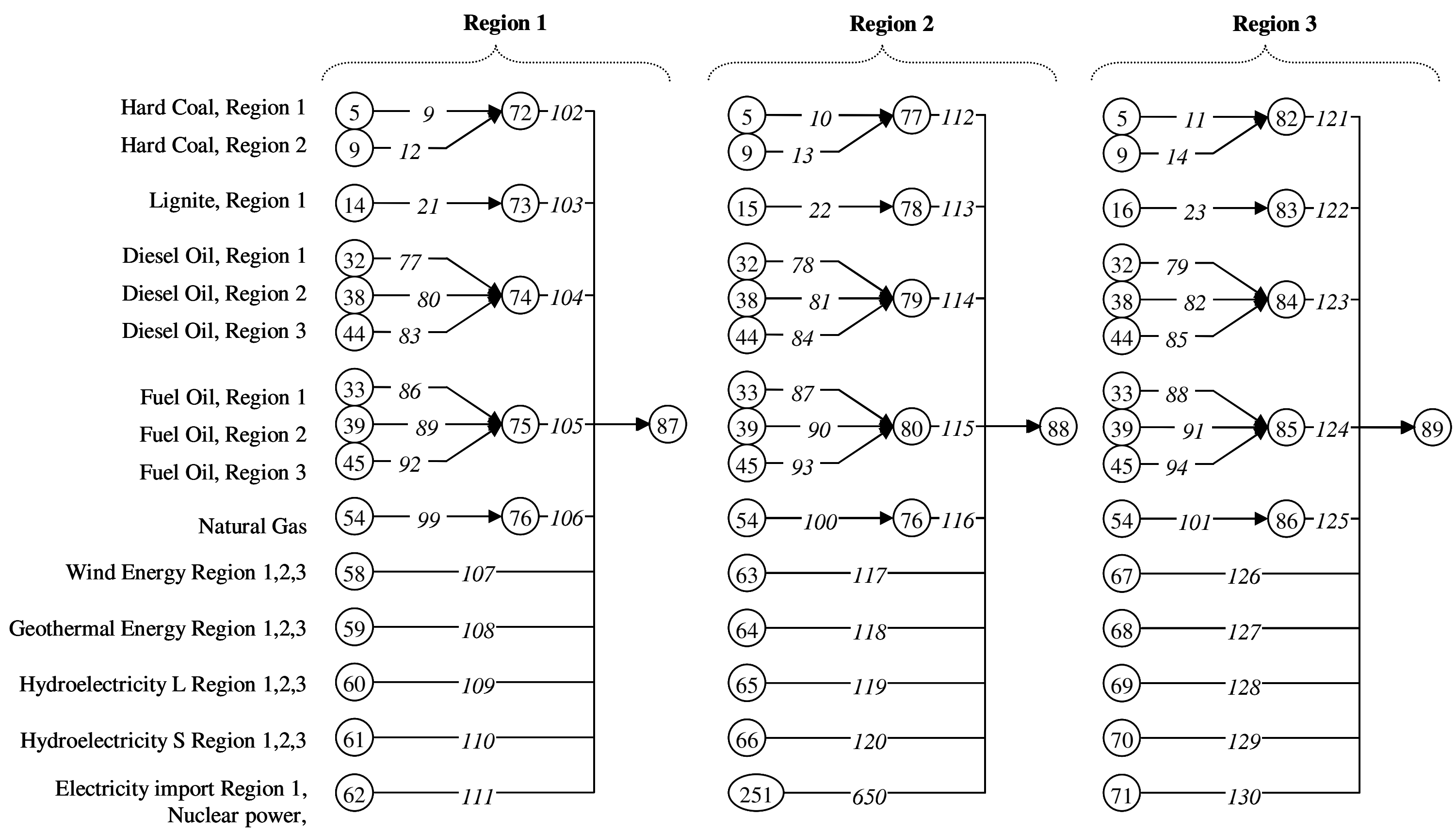


Figure 3.15 Electricity Generation System

The arcs 9, 10 and 11 show the hard coal transportation from Region 1 to the aggregated plant in Region 1, 2 and 3, respectively. Arcs 12, 13 and 14 show the same transportation from Region 2. Lignite, on the other hand is used by power plants in the same region, as they are situated close to the basins. Arcs 21, 22 and 23 show the transportation within the region, from the basin to the plant. The logic similar to the one for hard coal is valid for diesel oil and fuel oil. Arcs 77, 80 and 83 show transportation of diesel oil, from regions that are denoted on the resource node, to Region 1. Arcs 78, 81 and 84 show the transportation to Region 2, and arcs 79, 82 and 85 show the transportation to Region 3. Fuel oil is transported to Region 1, from regions 1, 2 and 3, respectively, by arcs 86, 89 and 92; to Region 2 by arcs 87, 90 and 93; and to Region 3 by arcs 88, 91 and 94. Natural gas is transmitted by the national pipeline network to the regions though arcs 99, 100 and 101.

Arcs 102 to 110 show the electricity generation in Region 1 by the aggregated hard coal, lignite, diesel oil, fuel oil, natural gas, wind, large hydroelectric and small hydroelectric power plants. Arc 111 shows electricity import from west to Region 1. Arcs 112 to 120 show the electricity generation in Region 2 in the same order. Arc 650 shows the power generated by a probable nuclear plant in Region 2. Arcs 121 to 129 show the electricity generation in Region 3 in the same order, and arc 130 shows the electricity import from east to Region 3. The properties of these plants were mentioned previously. The investment costs and the modeled type of costing will be explained in the mathematical model section.

3.3.2 Power Transmission

The electricity generated by the plants is transmitted through the country transmission system, which is operated by the state monopoly Turkish Electricity Transmission Corporation (TEİAŞ). This system, whose length and transformer capacity were presented previously, connects the power plants to the district distribution systems. 2-3% of the electricity generated is lost because of physical reasons. Electricity is transmitted through transmission lines with voltages ranging between 66 and 400 kV. This system is very large and complex. Since we aggregated the plants in a region by fuels and connected them to a single node assuming as if the electricity generated in a region were generated by a single massive plant; we treat the transmission system similarly and view it as a simple network between three regions. The capacity within a region is ignored, but the transmission capacities between the regions are embedded in the model. Table 3.19 shows the transmission system properties like length, capacity and investment cost, and Figure 3.16 shows the transmission system network in our model. See Appendix D for the calculation of these properties.

Table 3.19 Transmission System Properties

	Transmission R1↔R2	**Transmission R3↔R4**
Total length *(km)*	2,249	3,342
Capacity *(MVA)*	11,443	17,549
Investment cost *($ / MVA)*	19,430	22.146

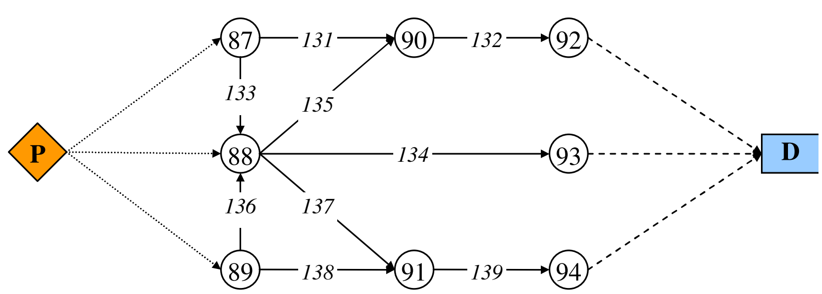


Figure 3.16 Electricity Transmission System

The transmission network begins with the end node for the electricity generation in each region. The generated electricity is then transmitted between the regions or within the region. Electricity transmission is from Region 1 to Region 2 (133), or Region 2 to Region 1 (135); and from Region 2 to Region 3 (137) or Region 3 to Region 2 (136); and electricity transmission within regions 1,2 and 3 (132, 134, 139 respectively) are the activities defined here. The arcs (131, 138) are dummy arcs which are costless and are put in order to prevent two way flow on the arcs define two way flows between regions.

3.4 Demand Sectors

There are five main demand sectors which are residential sector, transportation sector, industry sector, which has 6 sub-sectors, agricultural sector and non-energy use of fuels. The fuels which are extracted or imported and processed are consumed by one of these sectors to satisfy its energy demand. These fuels (and electricity) serve various functions in these sectors. They are both employed as factors of production, as in the blast furnaces in the iron and steel industry, and consumed directly for space heating and lighting purpose. From this point of view energy is both an intermediate good and a final good. In our model we do not differentiate the further use of energy resources. We simply define a total demand for energy resources for each demand sector, in terms of a common energy unit. Then the model is run to obtain an optimal mix of competing energy resources while satisfying the given demands for each sector. Only distinction is made between electricity and fuels. Along with a total energy demand for each sector an electricity demand is determined. So our model assumes infinite substitutability between competing fuels but allows none between fuels and electricity. This distinction or at least these type of distinctions, whether by bringing such restrictions or by setting minimum needs for certain fuels in an industry is a necessity of these models (LP, MIP) as they are incapable of describing the substitution effect between competing resources. This necessity has another reason as the model has an aim to provide information for power sector investment. Without the ability to represent resource substitutions properly, the model will be prevented from serving this purpose.

The size of the energy demand of each sector depends on various parameters. The first one is the size of that sector in the economy. We mentioned that energy consumption normally followed the GDP. The Figure 3.17 below shows the change of GDP and the energy demand between 1993 and 2003. When plotted against the individual sector demands and sector share in GDP, sam situation is observed. Another determinant is the energy intensity of the sector. Industries like iron and steel, petrochemicals and aluminum are energy intensive sectors. As the size of these sectors grows this affects the energy demand more. As our model has geographical coverage, a sectors development in a given region is a determinant for regional energy demand.

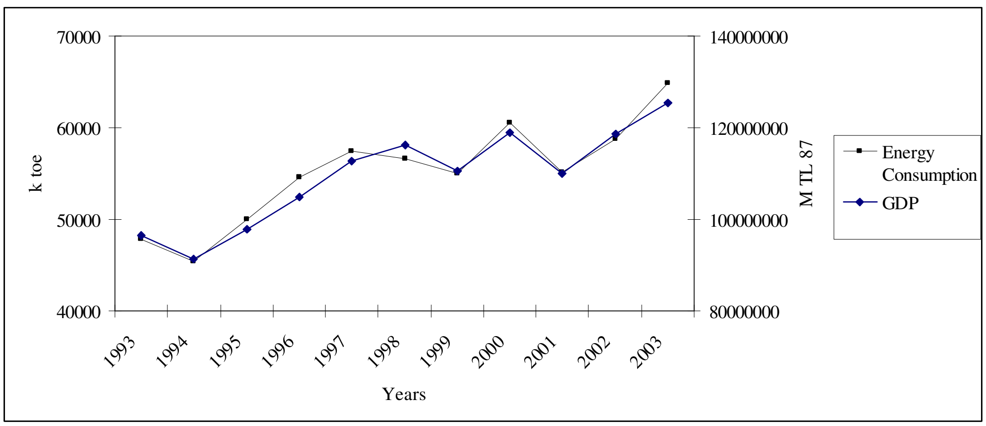


Figure 3.17 Energy Demand vs. GDP

The regional developments of sectors were found by using various TUIK statistics. For each sector a demand driver was decided and the projected final demand for a given sector was distributed between regions according to that driver's value for each region. Before continuing further, development of the energy demand in Turkey will be presented and discussed. Table 3.20 presents the energy demand between 1980 and 2003 and the projections to 2020, by total energy demand and electricity demand, with sector shares given in parentheses.

Table 3.20 Total Energy and Electricity Demand 1985 - 2020

	Total Demand	Residential	Industry	Transportation	Agriculture	Non-Energy
			Energy Demand *(k toe)*			
1985	32,730	14,438	9,779	6,195	1,506	812
		(44.1%)	*(29.9%)*	*(18.9%)*	*(4.6%)*	*(2.5%)*
1990	41,610	15,358	14,543	8,723	1,956	1,031
		(36.9%)	*(34.9%)*	*(21%)*	*(4.7%)*	*(2.5%)*
1995	49,975	17,596	17,372	11,066	2,555	1,386
		(35.2%)	*(34.8%)*	*(22.1%)*	*(5.1%)*	*(2.8%)*
2000	60,490	19,860	23,635	12,007	3,073	1,915
		(32.8%)	*(39.1%)*	*(19.8%)*	*(5.1%)*	*(3.2%)*
2003	66,796	19,634	29,583	12,395	3,086	2,098
		(29.4%)	*(44.3%)*	*(18.6%)*	*(4.6%)*	*(3.1%)*
2005	72,696	21,649	31,072	14,298	3,476	2,201
		(29.8%)	*(42.7%)*	*(19.7%)*	*(4.8%)*	*(3%)*
2010	99,402	29,019	43,585	19,915	4,370	2,513
		(29.2%)	*(43.8%)*	*(20%)*	*(4.4%)*	*(2.5%)*
2015	130,968	38,507	57,633	26,541	5,443	2,844
		(29.4%)	*(44%)*	*(20.3%)*	*(4.2%)*	*(2.2%)*
2020	170,292	47,549	78,732	34,039	6,753	3,219
		(27.9%)	*(46.2%)*	*(20%)*	*(4%)*	*(1.9%)*
			Electricity Demand *(GWh)*			
1985	29,108	9,576	19,008	213	311	-
		(32.9%)	*(65.3%)*	*(0.7%)*	*(1.1%)*	-
1990	45,670	16,688	28,062	345	575	-
		(36.5%)	*(61.4%)*	*(0.8%)*	*(1.3%)*	-
1995	65,724	27,384	36,337	490	1,513	-
		(41.7%)	*(55.3%)*	*(0.7%)*	*(2.3%)*	-
2000	96,140	45,664	46,686	720	3,070	-
		(47.5%)	*(48.6%)*	*(0.7%)*	*(3.2%)*	-
2003	111,766	52,120	55,099	890	3,657	-
		(46.6%)	*(49.3%)*	*(0.8%)*	*(3.3%)*	-
2005	129,650	60,300	64,277	1,060	4,013	-
		(46.5%)	*(49.6%)*	*(0.8%)*	*(3.1%)*	-
2010	201,652	94,093	100,882	1,651	5,026	-
		(46.7%)	*(50%)*	*(0.8%)*	*(2.5%)*	-
2015	307,071	143,430	154,940	2,593	6,108	-
		(46.7%)	*(50.5%)*	*(0.8%)*	*(2%)*	-
2020	434,565	195,302	227,767	4,047	7,449	-
		(44.9%)	*(52.4%)*	*(0.9%)*	*(1.7%)*	-

Turkey's energy demand has doubled since 1985. The electricity demand, on the other hand has quadrupled since then. When we look at the projections until 2020, we see that the energy demand will be 2.5 times the 2003 value and electricity demand in it will again be quadrupled. It's obvious that Turkey is facing a sharp increase in energy demand and it is forecast that this increase will continue in the middle term. Another obvious interpretation of the figures is that the share of industry demand in the total demand is almost continuously increased whereas the share of residential demand has decreased. This situation is reversed when electricity demand is considered. This may be due to increasing per capita income followed by increased spending on home electric appliances and increasing share of the commerce and services in the economy, whose demand is also considered under the residential demand.

As mentioned earlier, the energy demand forecast for sectors are distributed to the regions by using certain drivers (criteria) of energy consumption. After the brief introduction and explanation, the comparative percentages of fuel and electricity in each region will be tabulated.

The regional distribution criterion for fuel demand was the housing area in each region. As this demand mainly consisted of space heating, this criterion was found suitable to distribute the demand. Electricity demand for residential sector was distributed considering the electricity use in each region by summing the home use, commercial use, public sector use and street lighting. The criterion for transportation sector fuel demand was the number of cars in each region. Electricity demand, on the other hand, was distributed equally as this was mainly the demand of trains. The fuel demand for agriculture sector was distributed based on the number of tractors, as the only fuel consumed by agriculture sector is diesel which is used by agricultural machines and vehicles. The electricity demand was distributed based on the electricity consumption by agricultural watering, as this is the dominant electricity consuming way in agriculture. The distribution criteria up to now are gathered from the regional statistics of TUIK for 2003 [40]. See the complete list at the end of this chapter. Industrial demand was distributed by using the Energy Consumption in Manufacturing Industry Statistics 1999 - 2001 by TUIK (former DİE) [41]. We assumed that the consumption behavior in the statistics, which spans a three year period from 1999 to 2001, did not change between 2001 and 2003. The statistics are organized by industries. A reference industry for each industry sub-sector in our model is selected. For each industry the statistics showed the electricity and fuel consumption separately by each geographical region (following city borders as ours) of the country. Since our regional division is not similar to this, we used the city populations as a basis to fit the geographical regions' data to our regional frame. The reference industries and their groups in International Standard Industrial Classification of All Economic Activities (ISIC-Rev.2) Manufacturing Industry Classification are:

- Iron and Steel Industry → Group 371: *Iron and Steel Basic Industries*
- Chemicals and Petrochemicals Industry → Sum of the,
  - Group 3511: *Manufacture of basic industrial chemicals, except fertilizers*
  - Group 3513: *Manufacture of synthetic resins, plastic materials an manmade fibers except glass*
  - Group 352: *Manufacture of other chemical products*
  - Group 353: *Petroleum refineries*
  - Group 355: *Manufacture of rubber products*
  - Group 356: *Manufacture of plastic products not elsewhere classified*
- Cement Industry → Group 3692: *Manufacture of cement, lime and plaster*
- Sugar Industry → Group 3118: *Sugar factories and refineries*
- Fertilizer Industry → Group 3512: *Manufacture of fertilizers and pesticides*
- Non-Iron Metals Industry → Group 372: *Non-ferrous metal basic industries*
- Other Industry → *Rest of them*

The resulting regional and sectoral division is presented in Table 3.21. It simply tabulates the distribution of fuel consumption to each region for each industry, distribution of electricity consumption to each region for each industry and comparison of fuel consumption with electricity consumption for each industry (on the left of fuel and electricity percentages, in italics).

Table 3.21 Regions Shares in Fuel and Electricity Consumption and Comparison of Total Fuel and Electricity Consumption by Demand Sectors

Sectors		Fuel				Electricity		
		R 1	**R 2**	**R 3**		**R 1**	**R 2**	**R 3**
Residential	*77.2*	56.6	28.6	14.9	*22.8*	61.0	24.5	14.5
Transportation	*99.4*	55.5	33.1	11.3	*0.6*	33.3	33.3	33.3
Industry Sectors								
Iron-Steel	*79.0*	34.9	47.3	17.8	*21.0*	76.3	15.5	8.1
Chemical-Petrochemical	*94.2*	79.1	16.6	4.3	*5.8*	73.9	19.3	6.8
Cement	*90.7*	57.2	27.5	15.4	*9.3*	51.4	29.5	19.1
Sugar	*99.2*	23.8	51.5	24.7	*0.8*	23.4	47.2	29.4
Fertilizer	*92.1*	87.7	8.5	3.8	*7.9*	68.4	23.9	7.7
Non-Iron Metals	*62.3*	28.6	63.5	7.9	*37.7*	23.5	70.8	5.8
Other	*80.8*	72.0	22.1	5.9	*19.2*	70.9	19.2	9.9
Agriculture	*89.8*	50.4	35.6	14.1	*10.2*	29.0	43.9	27.1
Non-Energy	*100*	46.0	29.3	24.7	*0.0*	0.0	0.0	0.0

Finally, we would like to discuss the transportation activities. As stated before, crude oil is transported by tankers and oil pipelines, natural gas is transported by LNG tankers and pressurized pipelines and electricity is transmitted and distributed by power lines. The costs associated with these freight modes are known and are put in the model. However for land transportation of fuels by trucks and tanker trucks over an unknown distance (as origin and destination are not specified), this is unknown. As this is a complicated and extensive study calculation of transportation costs for land transportation was ignored.

On the other hand, as transporting a fuel within each region and between regions would bring different burdens, and the burden of transporting a high calorie fuel is not the same as the one of transporting a low calorie fuel, we estimated an efficiency parameter for each transportation type (a distance - fuel pair). Distance is determined by the transportation origin and destination. It has 9 different distances: from regions 1, 2 and 3 to regions 1, 2 and 3. And this is calculated for each fuel type. The basis of the calculations is the energy intensity of each freight mode in *btu/ton.mile* which is converted into *toe/ton.km.* This is simply the energy needed to carry a load of 1 ton over a mile (or kilometer). The calculations and the resulting efficiency estimations are presented in Appendix D.

3.4.1 Residential Sector

The residential sector consists of residential, public and commercial sector. It consumes all of the fuels except petroleum coke, gasoline, diesel oil, jet fuel and other oil. Although the reason is not known, this is taken as a sector characteristic and they are excluded from the consumption bundle of the sector. Table 3.22 shows the fuel mix of the residential sector by quantities and percentages as of 2003.

Table 3.22 Residential Sector Demand, Quantity and Composition

	Residential Sector	
	(toe)	*(%)*
Hard coal	633,810	3.2
Lignite	1,238,546	6.3
Coke	134,608	0.7
Wood &Biomass	5,748,270	29.4
LPG	2,190,455	11.2
Fuel oil	481,201	2.5
Natural gas	3,652,517	18.7
Electricity	4,482,309	22.9
Geothermal Heat	784,000	4.0
Solar Heat	231,000	1.2

The Figure 3.18 shows the residential sector network in our model by regions. Sector demands in regions 1, 2 and 3 are denoted by nodes 95, 96 and 97 respectively. Since the sector network for each region is the same only Region 1 network will be explained through out the demand sectors section. Understanding the other two networks will be straightforward. Hard coal, coke, lignite, fuel oil and LPG that are transported (140 – 152) from other regions or within the region are then used for heat generation (527 – 531). The transportation and consumption of natural gas is combined (153) and is shown by a single arc. Geothermal heating (154), solar heating (155) and consumed wood & biomass (514) are provided within the same region. The electricity consumed (188) by the region is received from the regional transmission system, so this arc simply the electricity distribution and consumption activity together.

3.4.2 Transportation Sector

Transportation can be differentiated into two or four by purpose and mode, respectively. Two purposes may be listed as freight transportation and passenger transportation. This sector can also be deepened by considering the freight modes (air, sea, road, rail), but in the model a total energy demand was assumed. Those situations, however, are modeled as constrains on the fuel use. In the transportation sector five fuel types – gasoline, diesel oil, fuel oil, LPG and jet fuel, and electricity is used. These fuels are transported (191 – 205) from another region or within the same region and then consumed by vehicles (542 – 546). The electricity is consumed by railway transportation (206) and is received from the regional transmission lines. Natural gas is also used for municipal passenger transportation in some cities but has an insignificant portion (< %0.1) in the overall demand. Table 3.23 shows the transportation sector's base year fuel mix by quantities and percentages. Figure 3.19 illustrates the transportation and consumption activities in the transportation demand sector.

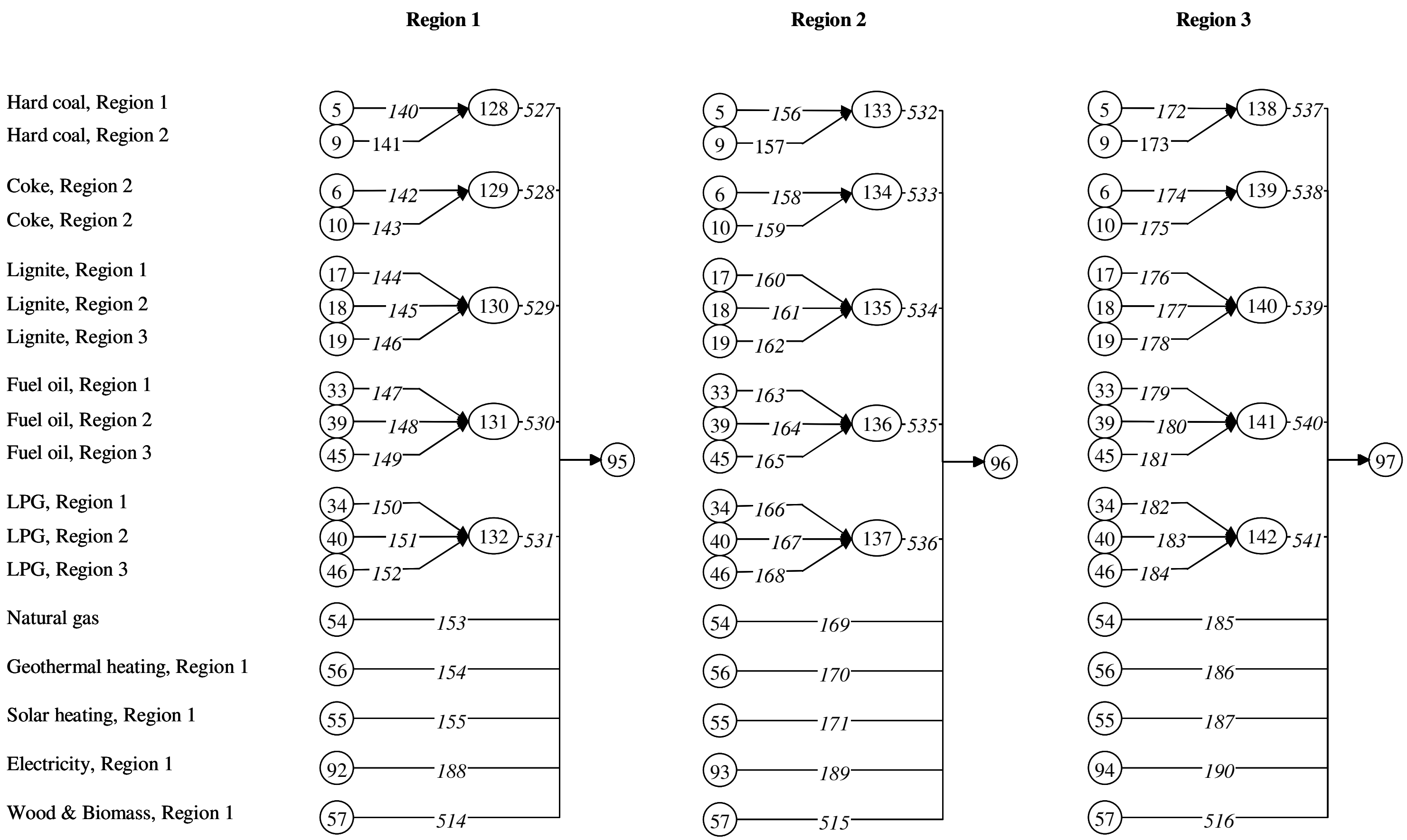


Figure 3.18 Residential Sector Network

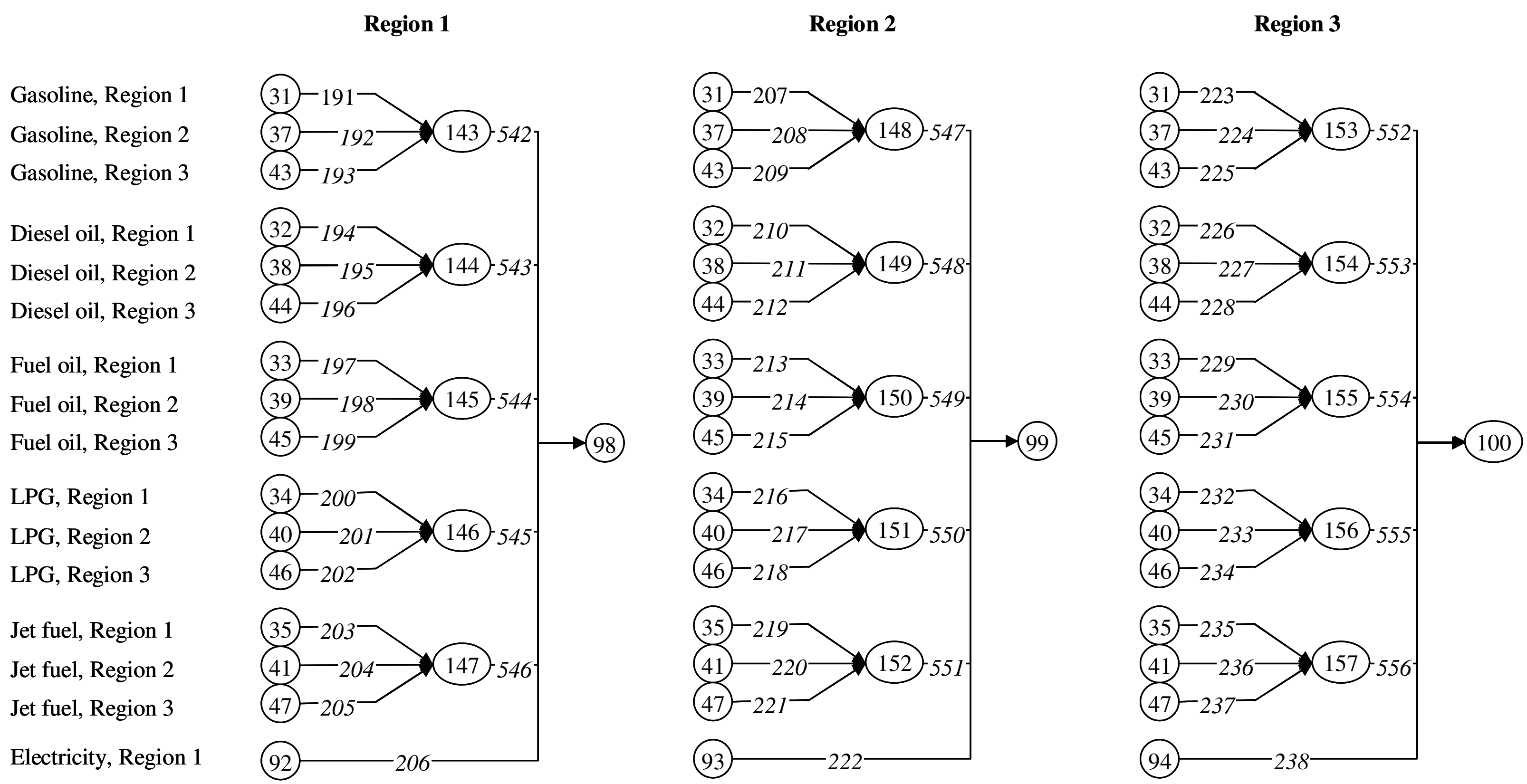


Figure 3.19 Transportation Sector Network

Table 3.23 Transportation Sector Demand, Quantity and Composition

	Transportation Sector	
	(toe)	*(%)*
LPG	1,373,098	11.1
Gasoline	3,171,560	25.5
Jet fuel	907,604	7.3
Diesel oil	6,786,935	54.7
Fuel oil	100,331	0.8
Electricity	76,540	0.6

3.4.3 Industrial Sector

The industrial sector is modeled, as previously mentioned, under seven industries. The transportation activities are modeled similar to the ones in residential and transportation demand sectors. Fuels are transported from other regions or within the same region and then are combined and consumed. Natural gas is supplied from the country network and the electricity is supplied from regional transmission system. Transportation and consumption of natural gas and distribution and consumption of electricity in a given region is thus modeled as single arcs.

3.4.3.1 Iron-Steel Industry

The iron and steel industry mainly consumes coke (557), which it produces on its own from hard coal as mentioned before. Another fuel that is consumed is fuel oil (558). Electricity is also used (244) in production. Other fuels are not consumed by the industry so they were not included in the model. Table 3.24 shows the quantities and percentages of fuels consumed in 2003 and Figure 3.20 demonstrates this sector's network.

3.4.3.2 Chemicals and Petrochemicals Industry

This industry sector comprises the chemicals and petrochemicals industries and petrochemical feedstock. The fuels consumed are hard coal (563), lignite (564), fuel oil (565) and other oil (566). Other oil is consumed as feedstock and constitutes a certain proportion of the total consumption. This is important as this consumption is not in the form of burning different from the others. As a result, for instance, it does not cause any gas emissions. Natural gas transportation and consumption (268) and electricity distribution and consumption (269) are modeled similar to the previous sectors. Table 3.25 shows the quantities and percentages of fuels consumed in 2003 and Figure 3.21 demonstrates this sector's network.

Table 3.24 Iron and Steel Industry Demand, Quantity and Composition

	Iron and Steel Industry	
	(toe)	*(%)*
Coke	2,125,558	62.8
Fuel oil	353,072	10.4
Other oil	80,423	2.4
Electricity	824,052	24.4

Table 3.25 Chemicals and Petrochemicals Industry Demand, Quantity and Composition

	Chemicals and Petrochemicals Industry	
	(toe)	*(%)*
Lignite	9,591	0.3
Fuel oil	759,940	25.5
Other oil	1,386,870	46.5
Natural gas	335,643	11.2
Electricity	493,393	16.5

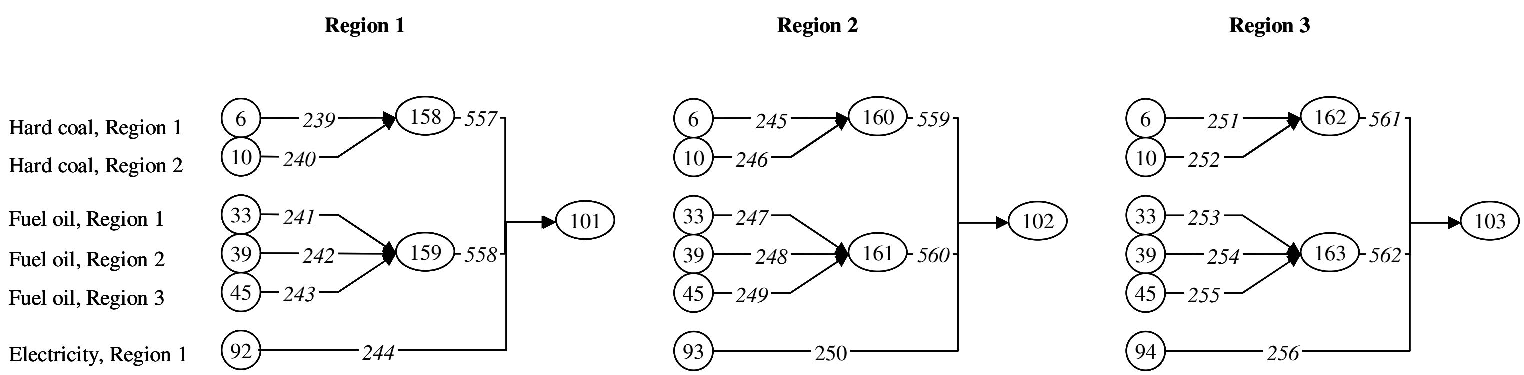


Figure 3.20 Iron and Steel Industry Sector Network

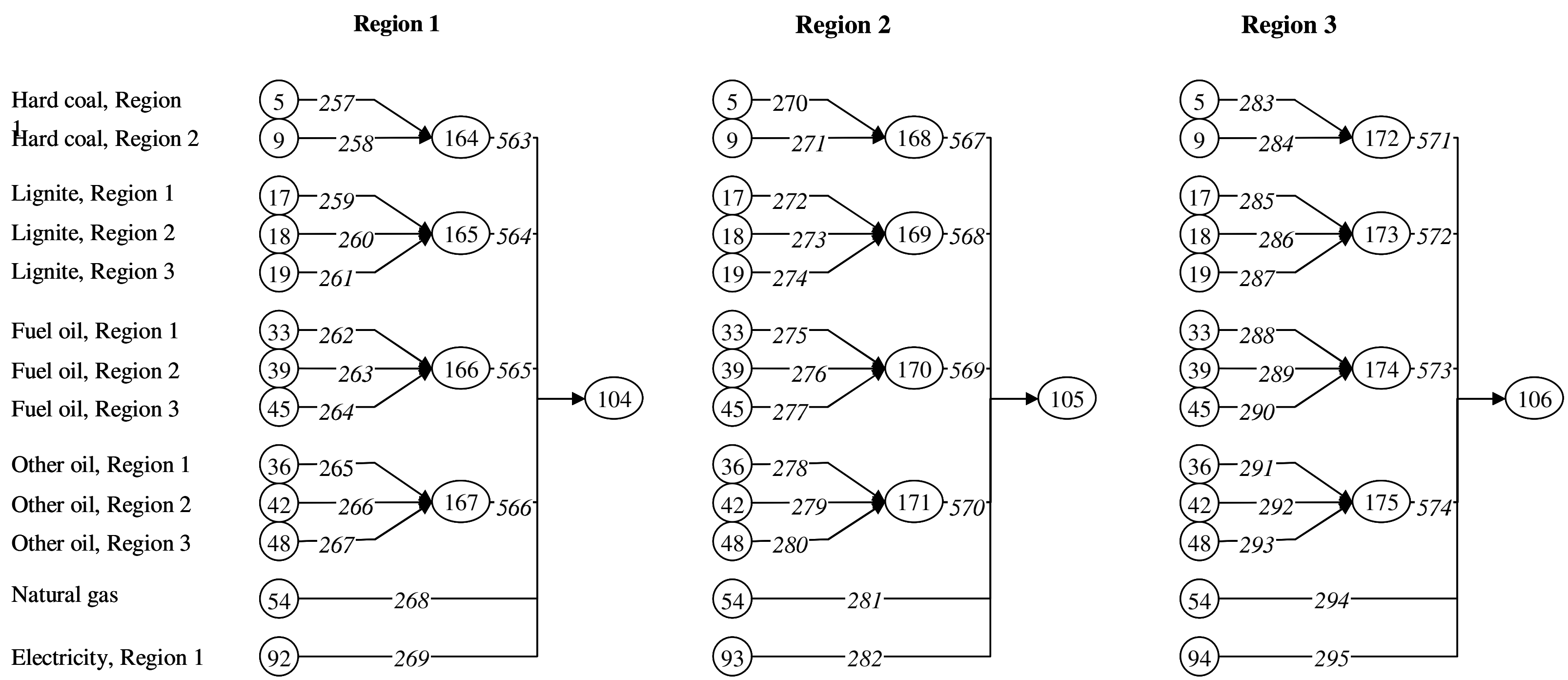


Figure 3.21 Chemicals and Petrochemicals Industry Sector Network

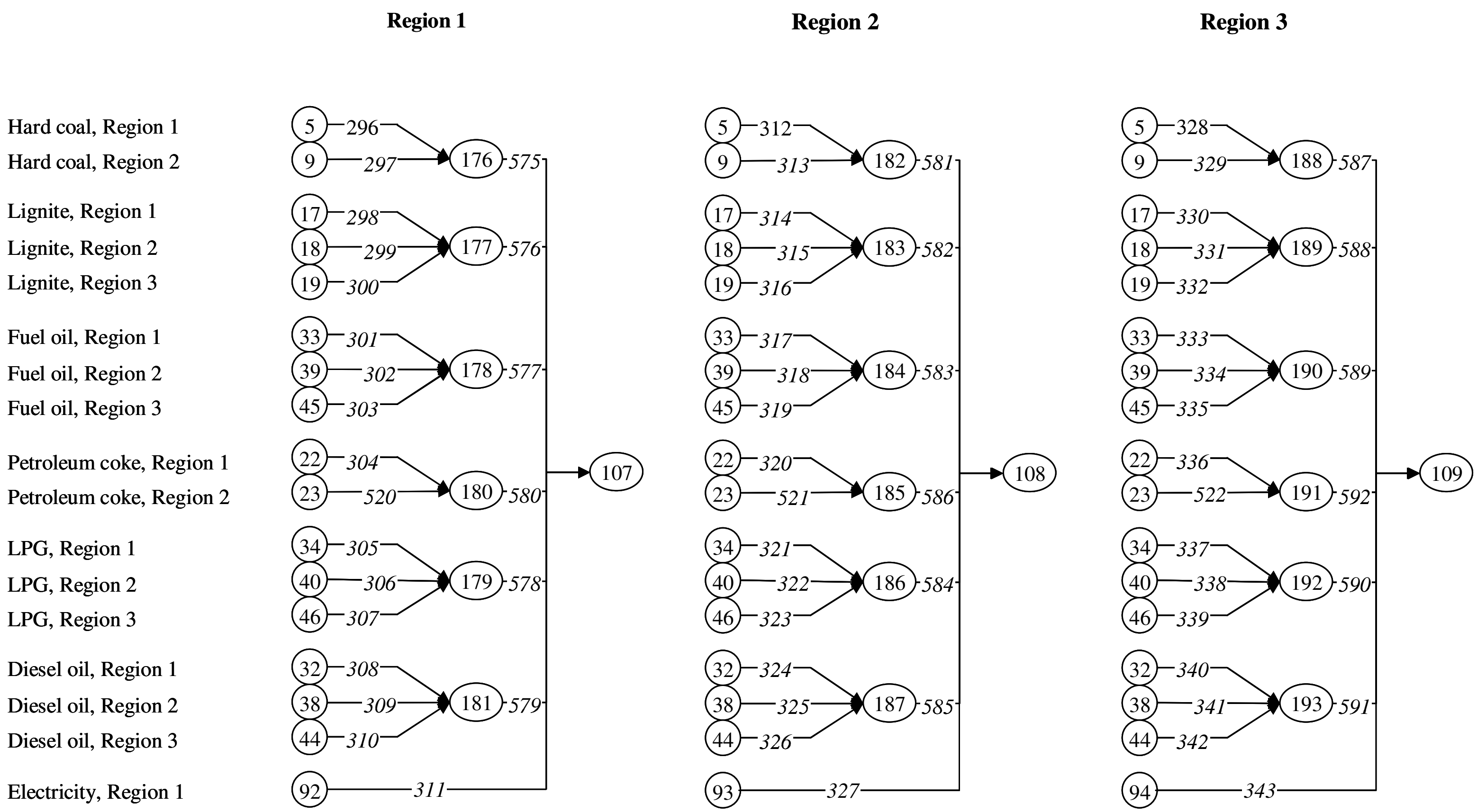


Figure 3.22 Cement Industry Sector Network

3.4.3.3 Cement Industry

This industry sector consumes hard coal (575), lignite (576), fuel oil (577), petroleum coke (580), LPG (578) and diesel oil (579). Electricity distribution and consumption (211) is modeled similar to the previous sectors. Figure 3.22 demonstrates the cement industry network in the model and Table 3.26 summarizes the consumption pattern of the industry in 2003.

Table 3.26 Cement Industry Demand, Quantity and Composition

	Cement Industry	
	(toe)	*(%)*
Hard coal	867,990	32.0
Lignite	474,617	17.5
Pet-coke	964,543	35.6
LPG	1,141	0.0
Diesel oil	1,968	0.1
Fuel oil	49,828	1.8
Natural gas	53,974	2.0
Electricity	295,733	10.9

3.4.3.4 Sugar Industry

This industry sector consumes hard coal (593), coke (595), lignite (594), fuel oil (596), natural gas (525) and electricity (526). Figure 3.23 demonstrates the sugar industry sector network in the model and Table 3.27 summarizes the consumption quantities and percentages in 2003 by resource type.

3.4.3.5 Fertilizer Industry

Fertilizer industry uses lignite (605), fuel oil (606) and natural gas (392) as fuels and uses electricity (381). The industry network is illustrated in Figure 3.24 and the demand structure 2003 is summarized in Table 3.28.

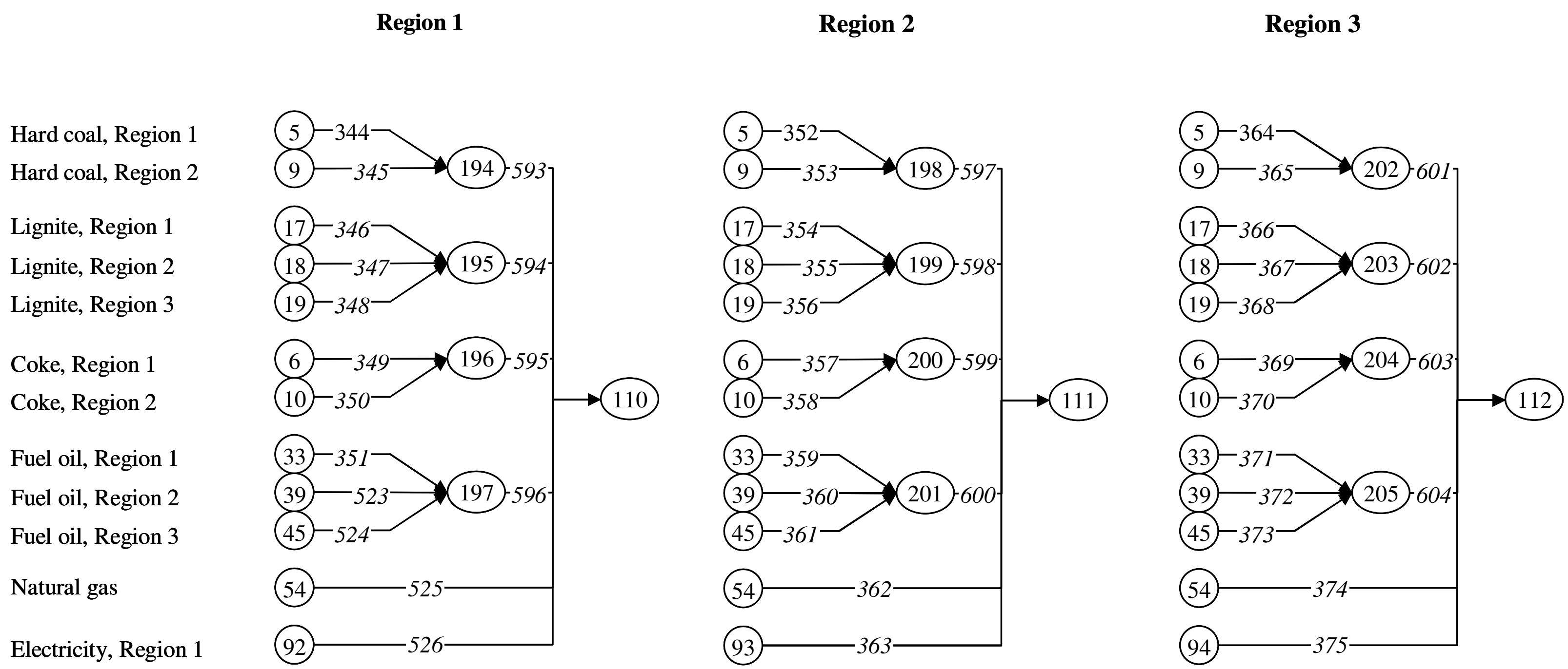


Figure 3.23 Sugar Industry Sector Network

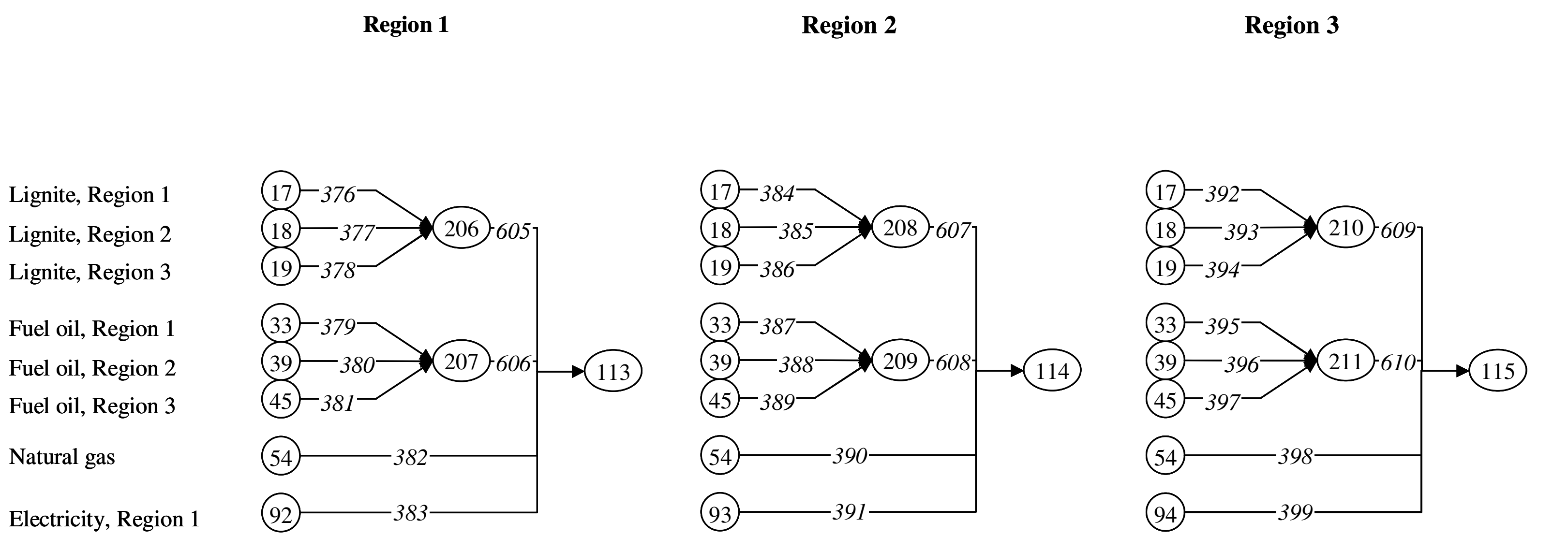


Figure 3.24 Fertilizer Industry Sector Network

Table 3.27 Sugar Industry Demand, Quantity and Composition

	Sugar Industry	
	(toe)	*(%)*
Hard coal	38,013	5.4
Lignite	280,953	39.9
Coke	46,200	6.6
Fuel oil	254,249	36.1
Natural gas	85,317	12.1
Electricity	0	0.0

Table 3.28 Fertilizer Industry Demand, Quantity and Composition

	Fertilizer Industry	
	(toe)	*(%)*
Lignite	5,682	1.0
Fuel oil	91,004	15.9
Natural gas	432,211	75.6
Electricity	42,869	7.5

3.4.3.6 Non-Iron Metals Industry

This industry is mainly the aluminum industry and it uses hard coal (611), coke (613), lignite (612), fuel oil (614), natural gas (410) and electricity (411). The sector network is illustrated in Figure 3.25. The consumption structure of the non-iron metals (non-ferrous metals) of the industry is summarized in Table 3.29.

3.4.3.7 Other Industries

This industry group is the sum of the rest of industries. They use hard coal (623), coke (625), lignite (624), petroleum coke (626), LPG (627), diesel (628), fuel oil (629), natural gas (453) and electricity (454). The sector network is presented in Figure 3.26 and the consumption structure in Table 3.30.

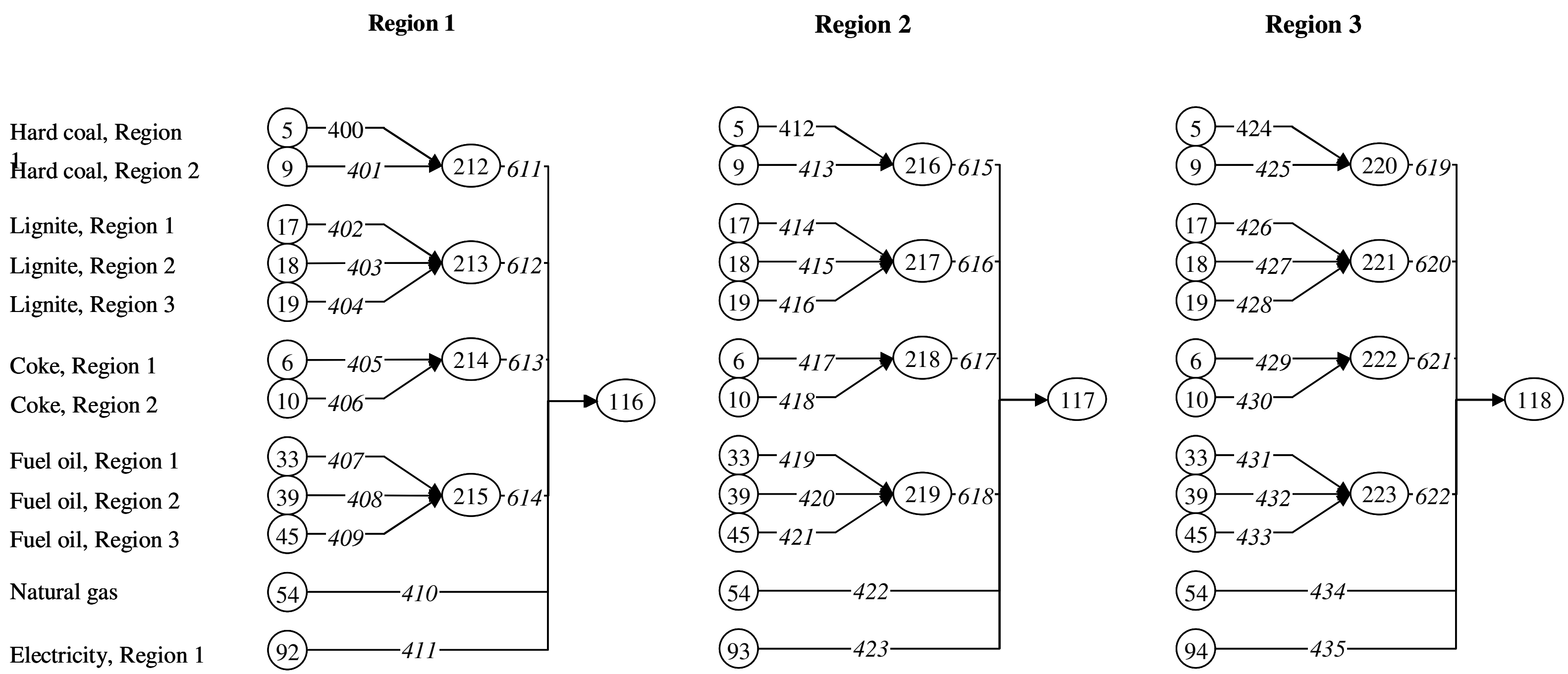


Figure 3.25 Non-Iron Metals Industry Sector Network

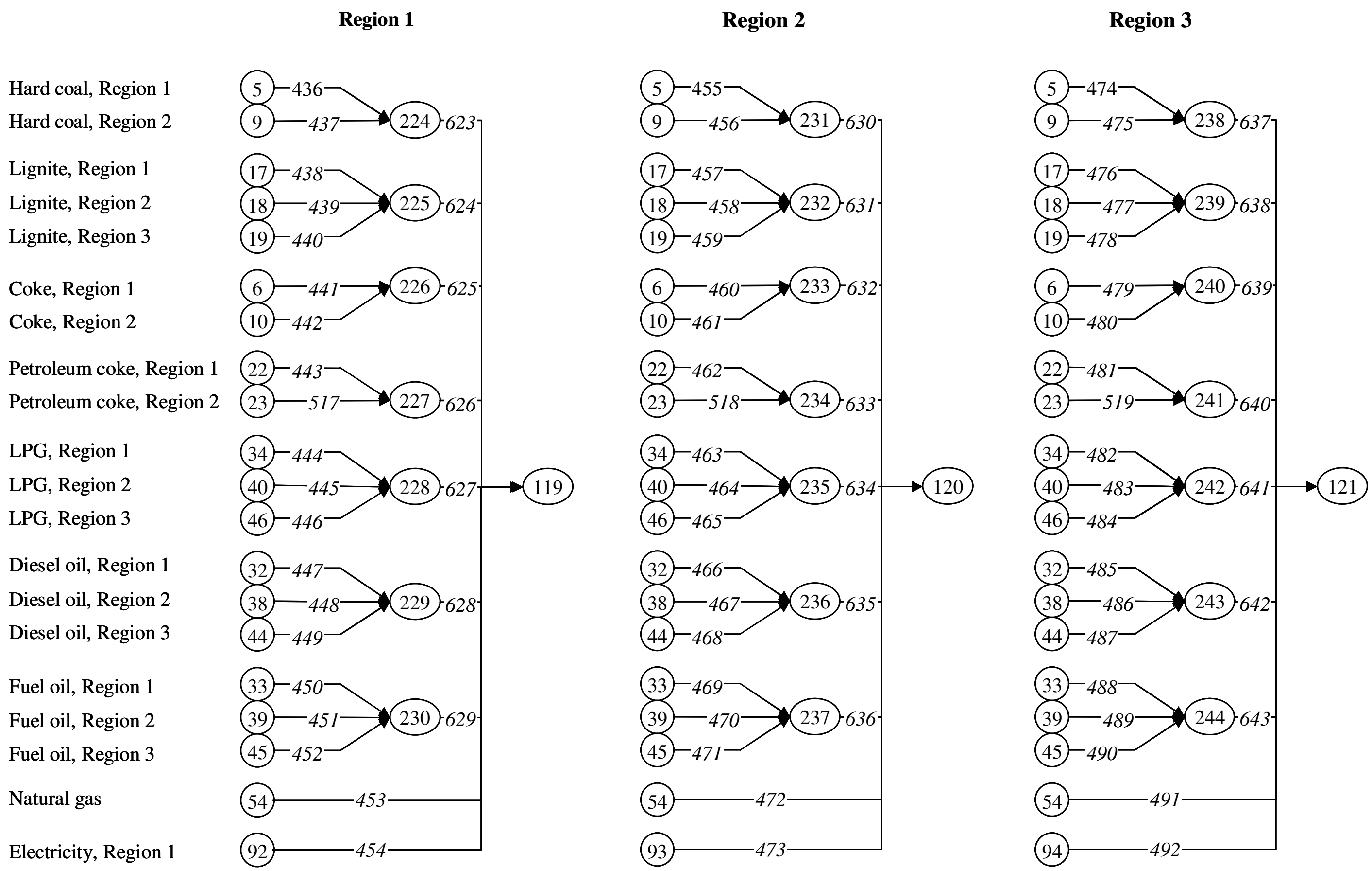


Figure 3.26 Other Industries Sector Network

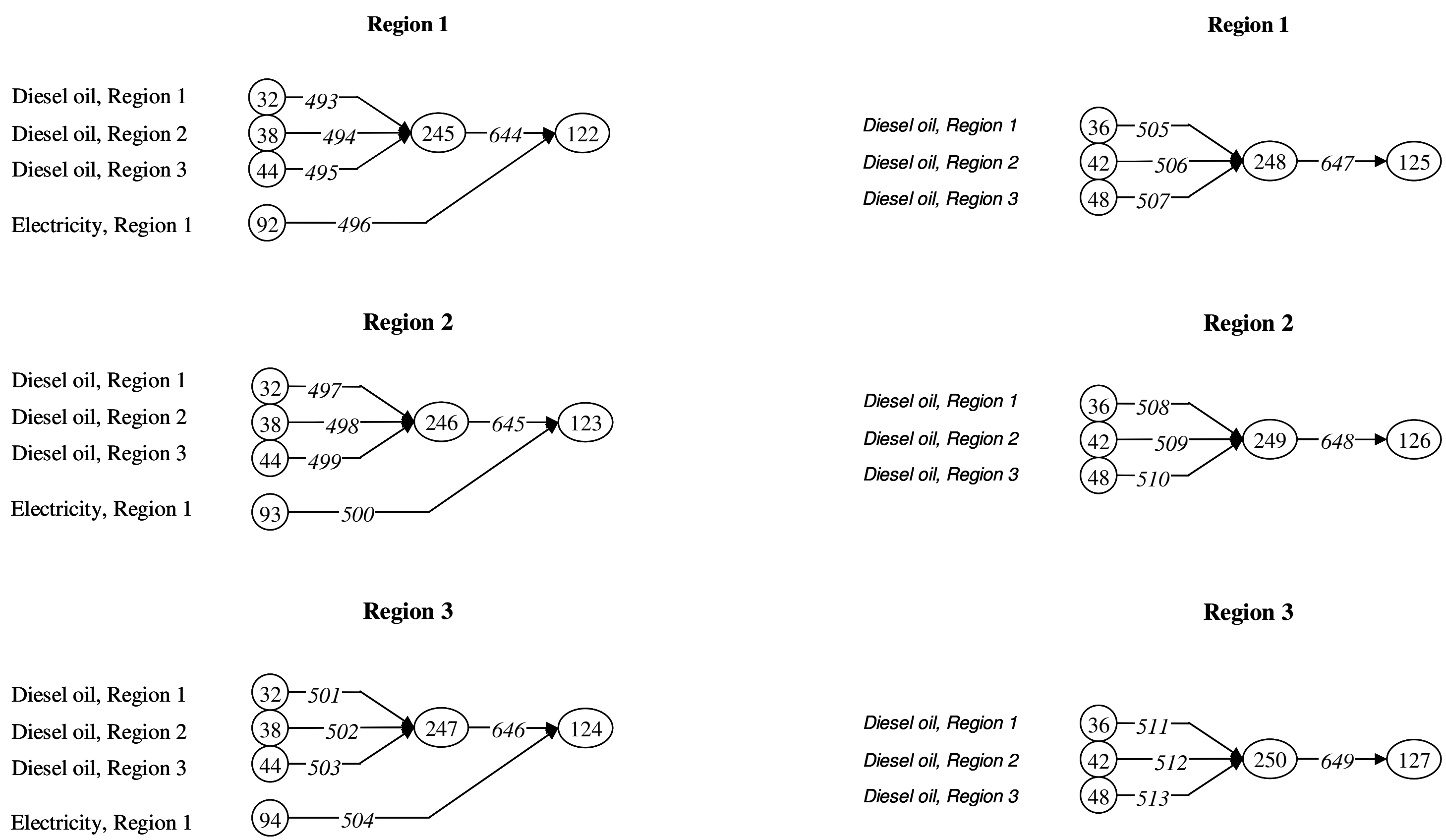


Figure 3.27 Agriculture Sector *(left)* and Non-Energy Uses *(right)* Networks

Table 3.29 Non-Iron Metals Industry Demand, Quantity and Composition

	Non-Iron Metals Industry	
	(toe)	*(%)*
Hard coal	51,859	5.3
Lignite	16,500	1.7
Coke	9,100	0.9
Fuel oil	265,979	27.4
Natural gas	360,957	37.2
Electricity	264,966	27.3

Table 3.30 Other Industries Demand, Quantity and Composition

	Other Industries	
	(toe)	*(%)*
Hard coal	4,721,668	32.4
Lignite	1,219,505	8.4
Coke	103,600	0.7
Pet-coke	355,971	2.4
LPG	455,445	3.1
Diesel oil	300,426	2.1
Fuel oil	1,581,397	10.9
Natural gas	3,100,767	21.3
Electricity	2,729,952	18.7

3.4.4 Agriculture Sector

Agriculture sector uses diesel oil (644) as fuel for agricultural machinery and electricity (496) mainly for agricultural watering. The sector network in the model is presented in Figure 3.27. The consumption quantities and percentages are in Table 3.31.

3.4.5 Non-Energy Uses

A major non-energy use of oil products is as pitch, by the road construction industry. This sector covers all non-energy uses except the petrochemical feedstock. This use denoted by the arc (647) for Region 1. The network is presented in Figure 3.27 together with agriculture sector. The consumption quantities for 2003 and their percentages are listed in Table 3.32.

Table 3.31 Agriculture Sector Demand, Quantity and Composition

	Agriculture Sector	
	(toe)	*(%)*
Diesel oil	2,777,164	89.8
Electricity	314,513	10.2

Table 3.32 Non-Energy Uses Demand, Quantity and Composition

	Non-Energy Uses	
	(toe)	*(%)*
Other oil	2,101,938	100.0

3.5 Gas Emissions

As a result of burning fuels, which are actually organic compounds named hydrocarbons, carbon dioxide (CO_2) and water is produced. Along with these two, other chemicals are also produced depending on the impurities that the burned fuel possesses or the burning process which does not let the fuel to be completely burned down. the human caused gas releases to the atmosphere is not limited with the burning of fuels. For instance agriculture is also a cause of emission, but in this model only energy related portion of the emissions are considered, which is the foremost cause among all. A group of gases are called the Greenhouse Gases (GHG) as they let the sunlight pas through them but not let the reflected light go back. As a result of this property radiation from the sun is kept in the atmosphere and causes it to warm. This effect is known as the greenhouse effect and is the cause of the phenomenon called global warming. most important of these gases are water vapor, CO_2, methane (CH_4) and nitrous oxide (N_2O) and are considered in our model along with three other polluting and poisonous substances: carbon monoxide (CO), nitrogen oxides (NO_X) and sulfur dioxide (SO_2).

As the global warming showed it effects, the control of these gases became more important. International commitment on preventing climate change has resulted in an agreed restriction on the emitted gases, actually the dominant one, CO_2. This agreement is the Kyoto Protocol, which requires the emissions to be reduced to 5% less than the base year level (1990 for most parties) until 2012. Turkey has not signed the protocol, yet. However as a result of the requirements by the UNFCCC, Turkey began working on gas emissions, quantities, emitters and natural sinks for gases, recently reported its first gas emissions inventory and declared the policies and taken steps with the National Communication to the UNFCCC.

In this chapter we will give the past data on gas emissions and explain how they are embedded in our model. As a developing country, Turkey's economy thus its need for energy enlarges continually. This increase causes the gas emissions to rise significantly. The largest gas emitter in the world is the USA, followed by China and Russian Federation (CDIAC 2003). Turkey ranks 24th in that list, with a CO_2 emission of 60 million tons of carbon (approximately 220 million tons of CO_2), below all big European countries. However, as per capita emissions are considered the rank is 103 with 0.84 ton of carbon per capita (approximately 3.08 ton of CO_2 per capita). The only European countries below Turkey are Latvia and Albania. Figure 3.28 and accompanying Table 3.33 present the GHG emissions (CO_2, CH_4 and N_2O) emissions of Turkey in total from 1990 [65]. We mentioned that energy system was not the only cause for the emissions, but it constituted around 77% of them. The following figure (Figure 3.29) presents the contributors of GHG emissions by sectors for 2004.

In the model these emissions are estimated by using an emission coefficient that is defined for each consumption activity, oil refining activities and power generation. The emission factors here were taken from the study report to World Bank (Conzelman 2002) and are the inputs to the BALANCE model developed for Turkish energy system. Each coefficient has the unit kg/giga-joules, thus calculates unit emission based on energy content. So the emission by every activity, for which a coefficient is defined, is calculated from the total energy consumption of that activity. The resulting emissions per activity are aggregated and the emission estimate for a given year is found. Resulting emission estimates will be mentioned in the results and analyses section.

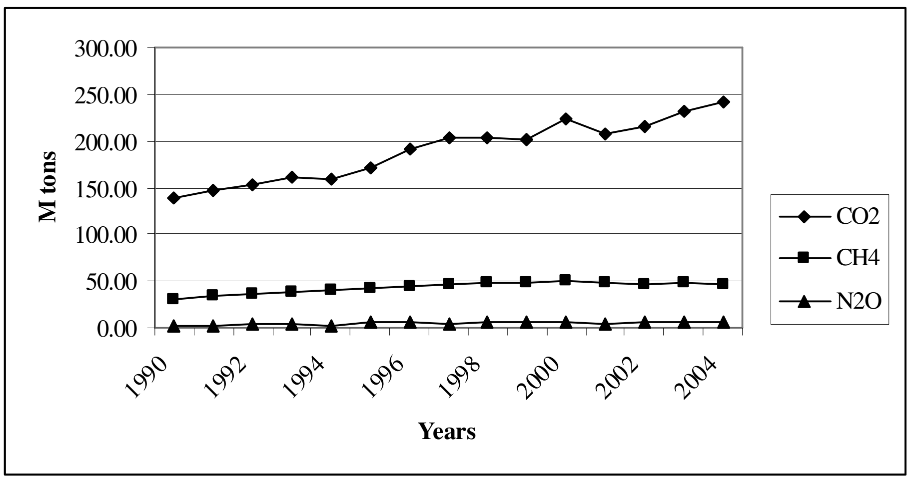


Figure 3.28 GHG Emissions 1990 – 2004

Table 3.33 GHG Emissions 1990 – 2003

	Gas Emissions			
				unit: million tons
	1990	**1995**	**2000**	**2003**
CO_2	139.59	171.85	223.81	230.99
CH_4	29.34	42.68	49.35	47.85
N_2O	1.26	6.33	5.74	5.25

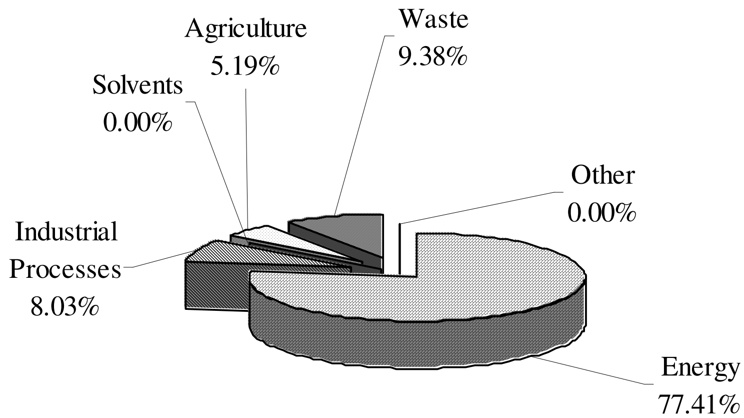


Figure 3.29 Breakdown of GHG Emissions in 2004 by Sector (source: [65])

CHAPTER 4

TURKISH ENERGY MODEL

In the previous section we have discussed the Turkish Energy System and its current position in terms of resources, consumption, and conversion capabilities. We also illustrated how this system (network) is represented in our model. Now we describe the mathematical model that we build on the mentioned network. We first present the sets (indices) used in the model, the model's parameters, model variables and finally the constraints and the objective that we wish to optimize.

Before continuing with the model description we would like to discuss some properties of the model, its purpose and the fundamental assumptions on which the whole structure is built.

To begin with, this model is an optimization model. As the name suggests, the model aims to optimize (that is minimize or maximize) a determined objective (objective function) without violating the existing set of restrictions (constraints). In our case, the aim is to minimize the cost of energy extraction, importing, conversion and transportation activities, and the costs of energy related investment to the national economy. The main output of the model is an optimal mix of consumed energy sources and a set of investment decision with a focus on power sector. The entire model is built on a network structure which is commonly known as a Reference Energy System (RES) and the restrictions are put in order to represent this network more properly. This network consists of 251 nodes that define an energy source at a location, and 650 arcs which denote a certain activity at a certain location. The model is a dynamic model as it has a planning horizon of 18 years from 2003 to 2020. It has geographical coverage as the country is divided into 3 regions to which the resources, conversion facilities and required demands are distributed. It is modeled in an MIP formulation, where binary variables are used to add the model more representing power for investment decisions. Finally the model's purpose is to draw a path towards a set goal and return an optimal consumption/production bundle with an optimal investment strategy seeking a least system cost for the allocation and investment problem.

4.1 Assumptions

The model is based on some fundamental assumptions. The following list with brief explanations summarizes these assumptions.

- All the parameters throughout the planning horizon are already known and certain. We optimize considering a single objective. Investments other than some power sector investments (see the constraints 20 to 26) are linear and divisible.

- Demands are *exogenous* and are *price irresponsive*, in other words, they are given and do not change as the price of the good changes. The energy demand of a sector in a region is predetermined based on the projections for future energy demand and the distribution principles explained in the previous section.

- Just as the energy demands, electricity demand for a sector in a region is exogenous and price irresponsive.

- It is assumed that the fuels are perfectly substitutable; however there is no substitution from electricity to fuels.

- For a given region, the percentage of a demand sector's demand in the overall regional demand does not change throughout the planning horizon. That is, *intersectoral development differences* are preserved.

- The percentage of a region's total demand in the overall demand does not change. That is, *interregional development differences* are preserved.

- The consumption amount of a fuel in a particular sector in a particular year is representative of the stock of consumption technologies using that fuel in that sector in that year; and this stock of technologies are fully utilized. That is, any demand increase in a sector will be satisfied by purchasing new equipment. The costs of purchasing are ignored and the decision among them is made based on the fuel costs. The consumption technology does not become obsolete or be disposed.

- Neither the existing nor the newly added facilities are closed in the planning horizon.

- The costs mentioned here are not *market prices in the country*. They don't include taxes, duties or profits of the entities in the system. However for imported goods the acquisition cost is simply the price of that good in the *world market*.

- The *costs* of extracting and processing the domestic resources, generating electricity and capacity investments are *constant*. They do not change over time. However, the importing costs are dynamic and are found based on the international projections for the world market price of the fuels.

- The efficiencies associated with the activities are constant. So the model simply ignores the effect of technological advancement and increasing efficiencies.

- The gas emission factors are constant over time. So the model does not reflect the environmental improvements in conversion and consumption activities.

- The land transportation activities (other than pipeline transport of natural gas or the pipeline transportation of crude oil are assumed to be costless. The differences between transportation modes and distances are represented by transportation efficiencies.

- It is assumed that the demand of the transportation sector does not include the demand for energy resources transportation. Similarly the demands of the conversion facilities (power plants, refineries etc.) are excluded in the final demands. All of the above are represented in the model by using the activity efficiencies.

4.2 Model Sets

i   Nodes of the network. As previously stated, each of them represents an energy source at a location in the energy system network. There are 251 nodes in the network. See Appendix B for the explanation of each node and the list elements of all defined subsets. $i \in I = \{1,\ldots,251\}$

$D(i) \subset I$	Set of the nodes which are named as demand nodes. They are the end nodes for the energy network.

$Trans(i) \subset D(i)$	Set of demand nodes which denote the demand nodes for the transportation sector.
$S(i) \subset I$	Set of nodes which are named as supply nodes. They are the start nodes for the energy network.
$Int(i) \subset I$	Set of nodes which are named as intermediate nodes. They are the nodes between supply and demand nodes.
$ElecN(i) \subset I$	Set of nodes which denote the nodes of the electricity sub-network in the energy network. They denote the nodes mentioned in the power sector section.
$ElecRN(i) \subset ElecN(i)$	Set of electricity nodes which denote the resource nodes in the electricity network, where resource is defined as the installed generation capacity in MW.
$ElecDN(i) \subset ElecN(i)$	Set of electricity nodes which denote the demand nodes, where demand is defined as the peak load of a region in MW.

j Arcs connecting the nodes, representing the activities/technologies converting the located energy source at the given node to another located energy source at the destination node, such as an electricity generation activity which converts the heat content of a fuel into electricity. There are 650 arcs in our network. For a full list of arcs with explanations see Appendix B. $j \in J = \{1,...,650\}$

$\text{Consum}(j) \subset J$	Set of arcs that denote the consumption activities in the demand sectors.
$\text{EConsum}(j) \subset \text{Consum}(j)$	Set of consumption activities which denote the electricity distribution/consumption in demand sectors. Recall that the consumption was not separated from the distribution.
$\text{TransD}(j) \subset \text{Consum}(j)$ $\text{TransG}(j) \subset \text{Consum}(j)$ $\text{TransL}(j) \subset \text{Consum}(j)$ $\text{TransJ}(j) \subset \text{Consum}(j)$	Set of consumption activities which denote the consumption of diesel oil, gasoline, LPG and jet fuel in the transportation sector, respectively.
$\text{Ref}^{n}(j) \subset J$	Set of activities which denote the refining activity (output) in refinery n. Recall that there are 4 refineries in Turkey. $n = \begin{cases} 1 & \text{İzmit} \\ 2 & \text{İzmir} \\ 3 & \text{Kıırıkkale} \\ 4 & \text{Batman} \end{cases}$
$\text{ElecA}(j) \subset J$	Set of activities which denote the electricity generation and transmission activities (arcs) in the electricity sub-network.
$\text{ElecAG}(j) \subset \text{ElecA}(j)$	Set of activities which denote the electricity generation by aggregate power plants in each region.
$\text{Elec}^{p}(j) \subset \text{ElecAG}(j)$	Set of activities which denote the electricity generation by a given plant type p; hard coal,

lignite, diesel, fuel oil, natural gas, wind, geothermal, large hydroelectric (projects) and small hydroelectric, respectively.

$\mathrm{Capacitated}(j) \subset J$	Set of activities which denote the arcs for which a capacity limit is defined.
$\mathrm{Geo}(j) \subset J$	Set of activities which denote generation and consumption of geothermal heat. Recall that for renewable resources mentioned in the resources section, the production, transportation and consumption was expressed by a single arc.
$\mathrm{Solar}(j) \subset J$	Set of activities which denote production and consumption of solar heat.

t Planning periods. Our planning horizon is from 1993 to 2020. So there are 18 years in our model. $t \in T = \{2003,...,2020\}$

l Substances whose emissions are calculated. As previously explained they are either GHG's or pollutant, poisonous substances. There are 6 gases whose emissions are considered in the model.
$l \in L = \{CH_4, CO, CO_2, N_2O, NO_x, SO_2\}$

h Large hydroelectric power plant projects. We defined 20 projects with capacities larger than 200 MW. $h \in H = \{1, 20\}$

4.3 Model Parameters

The full list of each model parameter defined below can be found in the model write up in Appendix E.

$D_{i,t}$ — Total demand for energy sources at a node i in year t, where $i \in D$. This parameter denotes the energy demand of a given demand sector in a given region. The unit is toe.

$DE_{i,t}$ — Total demand for electricity at a node i in year t, where $i \in D$. This parameter denotes the electricity demand of a given demand sector in a given region. The unit is toe.

S_i — Total supply of a resource at node i in year t, where $i \in S$. Since we did not define supply limits for supply nodes, but defined capacities, with the same aim, for the extraction arcs, we do not specify a value for this parameter.

E_j — Thermal efficiency of the activity j, representing the conserved percent of energy of the processed source. It is unitless.

$CInp_{j,t}$ — Non-energy input costs (fuel cost is included through extraction, import, processing and transportation costs) associated with an activity j in year t, which is calculated per unit of fuel processed. The parameter is associated with the original mass/volume unit in which the fuel is sold/purchased. (ie. m^3 for natural gas). It is then converted to the common unit, toe.

The parameters are entered in their original units (i.e. m^3, $\$/m^3$ for natural gas). Then they are converted into a form such that the energy unit I converted to toe. These are then used in the model. So the parameters named as "Inp" are inputs to calculate actual parameters.

$C_{j,t}$ Converted cost of activity j in year t per common energy unit, toe. The calculation is below.

$$C_{j,t} = \begin{cases} \text{CInp}_{j,t} \,/\, (\text{Unitcal}_j \text{ x } 1000 \text{ x KCALtoTOE}) & \text{ton} \\ \text{CInp}_{j,t} \,/\, (\text{Unitcal}_j \text{ x KCALtoTOE}) & \text{m}^3 \\ \text{CInp}_{j,t} \,/\, (\text{Unitcal}_j \text{ x KWHtoTOE}) & \text{kWh}^{1} \\ \text{CInp}_{j,t} \,/\, (0.45 \text{ x } 8760 \text{ x MWHtoTOE}) & \text{MWt} \\ \text{CInp}_{j,t} & \text{toe} \end{cases}$$

Unitcal_j Unit calorific value (kcal/kg or m^3) of the fuel flowing through arc j.

ArcCapInp_j Production (in terms of output produced) capacity of activity j in the base year in original units. This then converted to the common capacity unit, toe/year.

ArcCap_j Converted production (in terms of output produced) capacity of activity j in year t. In common units (toe).

$$ArcCap_j = \begin{cases} \text{ArcCapInp}_j \text{ x Unitcal}_j \text{ x } 1000 \text{ x KCALto TOE} & \text{ton} \\ \text{ArcCapInp}_j \text{ x Unitcal}_j \text{ x KCALto TOE} & \text{m}^3 \\ \text{ArcCapInp}_j \text{ x } 0.45_j \text{ x } 8760 \text{ x MWHto TOE} & \text{MWt} \\ \text{ArcCapInp}_j & \text{toe} \end{cases}$$

[1] Plant factor = 0.45; 8760 = 365 days x 24 hrs/days

ArcCapCInp_j Unit capacity expansion cost for activity j per original unit like \$/MW or \$/ton/year. This is then converted into the common cost unit, \$/toe.

ArcCapC_j Unit capacity expansion cost for activity j per common cost unit. The calculation is below.

$$CapC_j = c\begin{cases} \text{ArcCapCInp}_j \text{ / (Unitcal}_j \text{ x 1000 x KCALtoTOE)} & \text{ton} \\ \text{ArcCapCInp}_j \text{ / (Unitcal}_j \text{ x KCALtoTOE)} & \text{m}^3 \\ \text{ArcCapCInp}_j \text{ / (0.45 x 8760 x MWHtoTOE)} & \text{MWt} \\ \text{ArcCapCInp}_j & \text{toe} \end{cases}$$

ArcResInp_j Total reserve in original units defined for depletable natural resources. this is then converted into the common energy unit, toe.

ArcRes_j Converted total reserve in toe defined for a depletable natural resource.

$$ArcRes_j = \begin{cases} \text{Arc Re sInp}_j \text{ x Unitcal}_j \text{ x 1000 x KCALto TOE} & \text{ton} \\ \text{ArcCapInp}_j \text{ x Unitcal}_j \text{ x KCALto TOE} & \text{m}^3 \end{cases}$$

RenResInp_j Maximum annual production/extraction level in original units which is defined for renewable natural resources. This is in original units, so it is converted into the common unit toe/year.

RenRes_j Converted maximum annual production/extraction level in toes/year defined for renewable natural resources. The calculation is below.

$$RenRes_j = \begin{cases} \text{RenResInp}_j \text{ x } 0.45 \text{ x } 8760 \text{ x MWHtoTOE} & \text{MWt} \\ \text{RenResInp}_j & \text{toe} \end{cases}$$

Pfac_j The plant factor. It determines the percent of available working hours in which the plant can be operated. A plant may require periodic shutdowns or simply lack enough resource to operate (i.e. hydroelectric plants during summer).

PowCapInp_j Installed capacity of the aggregated power plant in arc j in original units (MW). This is converted to toe based on the plant factor and available working hours.

PowCap_j Estimated generation capacity of the aggregated power plant in arc j in common units (toe).

$$PowCap_{jt} = \{\text{PowCapInp}_j \text{ x Pfac}_j \text{ x } 8760 \text{ x MWHtoTOE}\}$$

PowCapCInp_j Unit capacity expansion cost for the aggregated power plant in arc j in \$/MW. This parameter is defined for the power plant types whose investment cost is linear. See the associated constraint for more information. This is turned into \$/toe.

PowCapC_j Estimated unit capacity expansion cost for the aggregated power plant in arc j in \$/toe. This parameter is defined for the power plants whose investment cost are defined to be linear.

$$PowCapC_j = \{\text{PowCapInp}_j \text{ / (Pfac}_j \text{ x } 8760 \text{ x MWHtoTOE)}\}$$

PowFixC_j Fixed component of the investment cost for the aggregated power plant in arc j in \$. This parameter is defined for the power plants for which investment cost is defined as (fixed cost component + linear variable cost)

$PowVarC_j$	Variable component of the investment cost for the aggregated power plant in arc j in \$/MW. (if investment cost is defined to be fixed cost + linear variable cost)
$HydroArc_h$	The arc that the hydroelectric power plant project h belongs to. This used in order to define the destination or origin node for an arc depending on the node arc incidence matrix.
$HydroCost_h$	The cost of the hydroelectric power plant project h in \$.
$HydroCap_h$	The capacity of the hydroelectric power plant project h in MW.
$HydroFac_h$	The plant factor of the hydroelectric power plant project h.
NuclearCost	The cost of nuclear plant in \$.
NuclearCap	The capacity of nuclear plant in MW.
NuclearFac	The plant factor of nuclear plant.
$MaxCap^p{}_t$	Maximum possible capacity addition to the plant type p in year t. In a given year the capacity added cannot exceed the 20% of the existing capacity.
$RefCapInp^n$	Installed processing (input) capacity of refinery n in tons.
RefCapC	Investment cost for capacity expansion in refineries in \$ / ton / year.

$Refmax^{n}{}_{j}$	Maximum output ratio of refinery n, relating output amounts by type, to the total output of the refinery, where $j \in Ref^{n}$.
$Basecomp_{j}$	The contribution of arc j to the total demand of the related node I in the base year.
$Peak_{t}$	Peak load estimation in year t.
$Peakcomp_{i}$	Share of node (region) i in the peak load as of 2003. The peak load is distributed by the regions.
$M_{i,j}$	Node arc incidence matrix representing the connections in the network. It's is a $\lvert I \rvert \times \lvert J \rvert$ matrix defined as follows: $M_{i,j} = \begin{cases} -1 & \text{if node i is the origin of arc j} \\ E_j & \text{if node i is the destination of arc j} \\ 0 & \text{if node i and arc j are not related} \end{cases}$
$MELEC_{i,j}$	Node arc incidence matrix representing the connections in the network. It's is a $\lvert ElecN \rvert \times \lvert ElecA \rvert$ matrix defined as follows: $MELEC_{i,j} = \begin{cases} -1 & \text{if node i is the origin of arc j} \\ 1 & \text{if node i is the destination of arc j} \\ 0 & \text{if node i and arc j are not related} \end{cases}$
$CapInpTrans^{1\leftrightarrow 2}$ $CapInpTrans^{2\leftrightarrow 3}$	Power transmission capacities as of 2003, between the regions 1 and 2, and 2 and 3 in MW. This id converted into toe by the formula below.

$CapTrans^{1\leftrightarrow 2}$ $CapTrans^{2\leftrightarrow 3}$ — Power transmission capacities as of 2003, between the regions 1 and 2, and 2 and 3 in toe. This found by summing the cut capacity along the region borders.

$$CapTrans^{..\leftrightarrow ..} = CapInpTrans^{..\leftrightarrow ..} \text{ x } 8760 \text{ x } MWHtoTOE$$

$CapCInpTrans^{1\leftrightarrow 2}$ $CapCInpTrans^{2\leftrightarrow 3}$ — Power transmission capacity expansion costs, between the regions 1 and 2, and 2 and 3 in \$/MW. This is then converted into \$/toe.

$CapCTrans^{1\leftrightarrow 2}$ $CapCTrans^{2\leftrightarrow 3}$ — Power transmission capacity expansion costs, between the regions 1 and 2, and 2 and 3 in \$/toe.

$$CapCTrans^{..\leftrightarrow ..} = CapCInpTrans^{..\leftrightarrow ..} / (8760 \text{ x } MWHtoTOE)$$

$Em_{l,j}$ — Amount of substance l emitted as a result of activity j. $kg / GJoule$

L_j — Useful life of the technology j. It is taken as 25 for each plant in the model.

r — Discount rate. 10%.

KCALtoTOE — Scalar converting Kcal to Toe. It is 0.0000001
KWHtoTOE — Scalar converting KWh to Toe. It is 0.0859781
MWHtoTOE — Scalar converting MWh to Toe. It is 0.0000859781
GJtoTOE — Scalar converting GJ to Toe. It is 0.023883

4.4 Model Variables

Positive Variables:

$X_{j,t}$	Amount of energy sent from node u to node v in year t, where activity j represents the arc (u,v) in the network. (in toe)
$Emission_{l,t}$	The total amount of gas l emitted in year t. (in tons)
$RefInv^{n}_{t}$	Refinery capacity expansion in refinery n in year t. (in toe)
$TransInv^{1\leftrightarrow 2}_{t}$ $TransInv^{2\leftrightarrow 3}_{t}$	Transmission capacity expansions between regions 1 and 2, and 2 and 3 in year t. (in MW)
$CapInv_{j,t}$	Capacity expansion in capacitated arc j in year t. (in toe)
$PowInv_{j,t}$	Capacity expansion in electricity generation arc j in year t. (in toe)
$Gencap_{j,t}$	Capacity in electricity generation arc j in year t (in MW)
$P_{j,t}$	Contribution of electricity generation arc j to the peak load in year t. (in MW)
$K_{i,j,t}$	Percentage of demand increase in node i from year t-1 to t, that is satisfied by arc j.

Binary Variables:

$OpenPlant_{j,t}$	0-1 variable telling whether to invest in the aggregated plant in arc j in year t, for those whose investment cost is defined to be fixed cost + linear variable cost.

$OpenHydro_{h,t}$ 0-1 variable telling whether to open the hydroelectric power plant named as project h in year t.

$OpenNuclear_{t}$ 0-1 variable telling whether to open the nuclear power plant named in year t.

4.4 Model Constraints

The first constraint on the model is the satisfaction of network flows. As each node is a demand, supply or intermediate node; it should either satisfy the demand (be greater than or equal to) or the supply (be less than or equal to) associated with it, or conserve the flow through it in any given year. The reader may refer to [66] for a simple model with only flow constraints for the application of node arc incidence structure.

$$\sum_j M_{i,j} X_{j,t} \geq \left\{ \begin{array}{ll} D_{i,t} & i \in D \\ -S_{i,t} & i \in S \\ 0 & i \in Int \end{array} \right\} \qquad \forall i,t \qquad (1)$$

In the model, total energy demand (fuel + electricity) and electricity demand were treated separately. This separation is essential in the investment planning for electricity as the peak loads for a given year is derived from the expected electricity consumption. This constraint satisfies for each arc that denotes *electricity consumption,* the demand for electricity in the associated *destination node* ($M_{i,j} > 0$). Note that the fuels are free to compute with each other and are assumed perfect substitutes, but they are not substitutable with electricity.

$$E_j X_{j,t} \geq DE_{i,t} \qquad \begin{array}{l} \forall j \in EConsum \\ \forall i \ni M_{i,j} > 0 \\ \forall t \end{array} \qquad (2)$$

In the model, the base year consumption is assumed to represent the existing stock of the energy consuming technology stock as of 2003. The following constraint equates the base year consumptions to the actual ones in 2003 for each arc that denotes *consumption*.

$$E_j \, X_{j,2003} \geq Basecomp_{\mathrm{j}} \, D_{i,t} \qquad \forall\, j \in Consum \quad \forall\, i \ni M_{i,j} > 0 \tag{3}$$

The model includes a flow-stock structure as in the inventory models. Constraint (4) states that the consumption amounts of a given fuel in a given year t-1 is kept fixed if once decided, and the allocation decision between fuels in year t is made on the *demand increase between t and t-1*. This is a result of the previous assumption above (3) that the consumption amount of a fuel in a given year represents the consumption technology stock using that fuel in that year. No obsolescence and full utilization are assumed. The next constraint guarantees that the demand increase is distributed between competing fuels.

$$E_j \, X_{j,t} \geq E_j \, X_{j,t-1} + K_{i,j,t}\left(D_{i,t} - D_{i,t-1}\right) \qquad \forall\, j \in Consum \quad \forall\, i \ni M_{i,j} > 0 \quad \forall\, t > 1 \tag{4}$$

$$\sum_{j \ni \mathrm{M}_{\mathrm{i,j}} > 0} K_{i,j,t} = 1 \qquad \forall\, i \in D \quad \forall\, t > 1 \tag{5}$$

The processing capacities of the refineries are limited with the capacity in a given year which is the sum of initial capacity and the sum of capacity increases until that year. Note that the index tt represents the same set as t, that is it is simply the planning period, t.

$$\sum_{j \in Ref^n} X_{j,t} \leq RefCapInp^n + \sum_{tt=2003}^{t-1} RefInv^n{}_{tt} \qquad \forall\, n \in \{1,2,3,4\} \quad \forall\, t \tag{6}$$

A refinery is designed to refine crude oil to form different refined oil products. Recall that the composition of the output (percentages of each refined oil product) is different for each refinery. Similarly the percentage of an oil product in a given refinery may change. In order to deal with this, a *refinery maximum* for each fuel-refinery pair is defined. Constraint (7) states that the ratio of a refined product to the total production of the refinery is limited by the *maximum percentage* of that refined product in that refinery.

$$E_j X_{j,t} \leq RefMax^n{}_j \left(\sum_{j \in Ref^n} E_j X_{j,t} \right) \qquad \forall n \in \{1,2,3,4\} \quad \forall j \in Ref^n \quad \forall t \tag{7}$$

The capacity addition to a refinery's existing capacity is limited. Constraint (8) states that it cannot exceed the capacity of the previous year more than 20%.

$$\begin{aligned} &\mathrm{RefCapInp}^{\mathrm{n}} + \sum_{\mathrm{tt}=2003}^{\mathrm{t-1}} \mathrm{RefInv}^{\mathrm{n}}{}_{\mathrm{tt}} \leq \\ &1.2\left(\mathrm{RefCapInp}^{\mathrm{n}} + \sum_{\mathrm{tt}=2003}^{\mathrm{t-2}} \mathrm{RefInv}^{\mathrm{n}}{}_{\mathrm{tt}} \right) \end{aligned} \qquad \forall n \in \{1,2,3,4\} \quad \forall j \in Ref^n \quad \forall t \tag{8}$$

Constraint (9) states that the total emission of a given gas in a given year is the sum of all emissions from each emission creating activity in that year. Since the emission factor is given as kg/GJ it is converted to kg/toe.

$$Emission_{l,t} = \left(\sum_j Em_{l,j}\, X_{j,t} \right) / \, GJtoTOE \qquad \forall l,t \tag{9}$$

If an arc has a specified capacity limit, the flow through that arc in a given year is limited by the initial capacity of that arc and capacity additions up to that year.

$$E_j\, X_{j,t} \leq ArcCap_j + \sum_{tt=2003}^{t-1} CapInv_{j,tt} \qquad \forall j \in Capacitated \quad \forall t \tag{10}$$

Depletable resources have reserves. So the constraint (10) says that the total extraction of a depletable resource throughout the planning horizon cannot exceed the reserve of that resource.

$$\sum_{t=2003}^{2020} E_j X_{j,t} \leq ArcRes_j \qquad \forall j \in Capacitated \qquad (11)$$

Domestic crude oil transported to refineries in regions 1 and 2; and crude oil (domestic and imported) transport to refinery in region 2 are limited by the pipeline capacities of Batman-Ceyhan and Ceyhan-Kırıkkale oil pipelines, respectively. The capacity of the first pipeline is 3.5 million ton/year and the second pipeline has a capacity of 5 million. The following two constraints (12) and (13) state it, respectively.

$$\sum_{j=27}^{29} X_{j,t} \leq 3500000 \qquad (12)$$

$$X_{29,t} X_{33,t} \leq 5000000 \qquad (13)$$

Renewable resources have their annual maximum reserve limits. These three constraints state it respectively for small hydroelectric plants (net of remaining hydraulic reserve and projects), geothermal and solar.

$$\sum_t E_j X_{j,t} \leq RenRes_j \qquad \begin{array}{l} \forall j \in Elec^{H2} \\ \forall j \in Geo \\ \forall j \in Solar \end{array} \qquad (14)$$

Additions to generation capacity of a certain plant type are limited by the annual allowable increase defined for that plant type (15). For hydroelectric power plant projects this is different. In a given year at most 2 of the hydroelectric power plant projects may be realized (16).

$$\sum_{j \in Elec} \left(GenCap_{j,t} - GenCap_{j,t-1} \right) \leq MaxCap^{p}{}_{t} \qquad \forall p,t \tag{15}$$

$$\sum_{h} \mathrm{OpenHydro}_{h,t} \leq 2 \qquad \forall t \tag{16}$$

Generation capacity of a given aggregated plant in a given region is the sum of the initial capacity and the capacity additions up to that year. The capacity additions may either be linear or stepwise (for projects). The first constraint (17) is for following equations are for hard coal (HC) lignite (L), diesel, (D), fuel oil (FO), natural gas (NG), wind (W), geothermal (G) and small hydroelectric (H2) power plants. The capacity increase is defined to be linear for them.

The large hydroelectric – project (H1), which is shown by constraint (18), and nuclear power plant which is shown by constraint (19), are defined as projects, therefore their capacity increase is stepwise.

$$GenCap_{j,t} = PowCapInp_{j} + \left(\sum_{tt=2003}^{t-1} PowInv_{j,tt} \right) / \left(MWHtoTOE \; x \; 8760 \; x \; Pfac_{j} \right) \tag{17}$$

$$\forall \mathrm{j} \in \mathrm{Elec}^{\mathrm{p}}$$
$$\forall \mathrm{p} \in \left\{ \begin{matrix} \mathrm{HC, L, D, FO,} \\ \mathrm{NG, W, G, H2} \end{matrix} \right\}$$
$$\forall \mathrm{t}$$

$$GenCap_{j,t} = PowCapInp_{j} + \left(\sum_{h} \sum_{tt=2003}^{t-1} HydroCap_{h} \; x \; OpenHydro_{h,tt} \right) \tag{18}$$

$$\forall j \in Elec^{H1}$$
$$\forall h \ni HydroArc_{h} = j$$
$$\forall t$$

$$GenCap_{650,t} = PowCapInp_{650} + \left(\sum_{tt=2003}^{t-1} NuclearCap \; x \; OpenNuclear_{tt} \right) \tag{19}$$

$$\forall t$$

The electricity that a given aggregated plant can generate in a given year is limited by the initial capacity of that plant and the capacity additions up to that year. Note that for the plant types whose investment cost is defined to have a fixed and a variable cost component, the constraint guaranteeing the fixed cost to be incurred follows the capacity limit constraint. For hydroelectric plants and nuclear plants which are modeled as projects, the uniqueness constraint (not able to open a given plant more than once) follows the capacity limit constraint. Refer the objective function to see how the costs of these investments are incurred. Also note that the capacity of a plant in MW is converted to toe by multiplying it with the plant factor, the available working hours in a year (365 x 24 =8760) and the coefficient converting MWh to toe.

- **Linear Investment Cost Type:**

The investment costs for diesel oil, fuel oil, wind, geothermal and small hydroelectric power plants are linear. Their investment cost is defined by a single parameter in \$/MW. Constraint (20) states that the capacity of such a plant will increase linearly and the maximum attainable generation of that power plant is bounded by that capacity.

$$\mathrm{E}_{\mathrm{j}}\,\mathrm{X}_{\mathrm{j,t}} \leq \mathrm{PowCap}_{\mathrm{j}} + \sum_{\mathrm{tt}=2003}^{\mathrm{t-1}} \mathrm{PowInv}_{\mathrm{j,tt}} \qquad \begin{array}{l} \forall j \in Elec^{p} \\ \forall p \in \{D, FO, W, H2\} \\ \forall t \end{array} \tag{20}$$

- **Fixed Cost + Linear Variable Cost Type:**

The investment cost of hard coal, lignite and natural gas plants have both a fixed and a variable cost component. Constraint (21) states that the capacity of such a plant will increase linearly, and the electricity generation ($E_j\,X_{j,t}$) is limited by that capacity; and constraint (22) adds that for any capacity increase (PowInv > 0) the fixed cost for investment should be incurred.

$$. E_j X_{j,t} \leq PowCap_j + \sum_{tt=2003}^{t-1} PowInv_{j,tt} \qquad \forall j \in Elec^p \quad \forall p \in \{HC, L, NG\} \quad \forall t \tag{21}$$

$$PowInv_{j,t} \leq \infty \, OpenPlant_{j,t} \qquad \forall j \in Elec^p \quad \forall p \in \{HC, L, NG, H2\} \quad \forall t \tag{22}$$

- **Large Hydroelectric Power Plant Projects:**

As it was previously explained in the power sector section the large hydroelectric power plants (Capacity > 200 MW) are modeled as projects. That's why the capacity increase for those projects is not linear but step wise. As the constraint (23) suggests the generated electricity is limited by the capacity at that year. And the capacity is defined as the initial capacity plus the capacities of projects which are realized up to that year. Constraint (24) guarantees that a project is realized at most once during the planning horizon.

$$E_j X_{j,t} = PowCap_j + \sum_{h \ni HydroArc_h = j} \sum_{tt=2003}^{t-1} HydroCap_h \; HydroFac_h \; 8760 \; OpenHydro_{h,tt} \tag{23}$$

$$\forall j \in Elec^p \quad \forall p \in \{H1\} \quad \forall t$$

$$\sum_{tt=2003}^{2020} OpenHydro_{h,tt} \leq 1 \qquad \forall h \tag{24}$$

- **Nuclear Power Plant Project:**

The nuclear power plant project is treated in the same way as the large hydroelectric power plant projects. Constraint (25) limits the generation with the capacity of the nuclear plant, while constraint (26) guarantees that the nuclear plant is opened at most once during the planning horizon.

$$E_{650}\ X_{650,t} = PowCap_{650} + \sum_{tt=2003}^{t-1} NuclearCap\ x\ NuclearFac\ x\ 8760\ x\ OpenNuclear_{tt} \qquad \forall t \qquad (25)$$

$$\sum_{tt=2003}^{2020} OpenNuclear_{tt} \leq 1 \qquad (26)$$

The peak demand satisfaction is similar to the first group of equations, now defined for the electricity sub-network. The peak load contribution is defined as the portion of transmission capacity committed at the peak load moment, for the transmission lines; and the portion of generation capacity committed at the peak load moment, for the power plants. Constraint (27) simply states that the demands of each region in terms of peak load is satisfied conserving the flow. However, there is a constant of 1.15 that requires the total existing capacity should be 15% larger than the peak load. This constant is found by averaging the ratio of total installed capacities to the peak loads since 1970. The -∞ is put there as the commitments of plants are explained by constraints (30) and (31).

$$\sum_{j \in \mathrm{ElecA}} \mathrm{MElec}_{i,j}\ \mathrm{P}_{j,t} \geq \left\{ \begin{array}{ll} 1.15\ \mathrm{x\ PeakComp}_i\ \mathrm{x\ Peak}_t & \text{demand node} \\ -\infty & \text{supply node} \\ 0 & \text{intermediate node} \end{array} \right. \qquad (27)$$

$\forall i \in ElecN$

$\forall t$

The power transmission between regions is limited with the capacity of the transmission line between those regions. Constraint (28) shows the limitation between regions 1 and 2, while constraint (29) shows the one between 2 and 3.

$$P_{133,t} + P_{135,t} \leq CapInpTrans^{1\leftrightarrow 2} + \sum_{tt=2003}^{t} TransInv^{1\leftrightarrow 2}{}_{tt} \qquad \forall t \qquad (28)$$

$$P_{136,t} + P_{137,t} \leq CapInpTrans^{2\leftrightarrow 3} + \sum_{tt=2003}^{t} TransInv^{2\leftrightarrow 3}{}_{tt} \qquad \forall t \qquad (29)$$

The peak demand contribution of a plant is at most the installed capacity in year t

$$\mathrm{P}_{\mathrm{j,t}} \leq \mathrm{GenCap}_{\mathrm{j,t}} \qquad \forall j \in ElecAG \quad \forall t \qquad (30)$$

Since the modes in transportation is not included in the model, these constraints state that the current composition of transportation modes will be conserved. Therefore jet fuel (air transportation) will have the same percentage as it had in the base year (31); diesel oil (road freight/mass passenger transportation) will remain at least equal to the percentage in the base year (32); gasoline, diesel oil and LPG will compete for passenger (personal) transportation and their sum will be equal to the total base year percentages of these fuels (33, 34, 35).

$$E_j \; X_{j,t} = BaseComp_j \; D_{i,t} \qquad \forall j \in TransJ \quad \forall i \ni M_{i,j} > 0 \quad \forall t \qquad (31)$$

$$E_j \; X_{j,t} \geq BaseComp_j \; D_{i,t} \qquad \forall j \in TransD \quad \forall i \ni M_{i,j} > 0 \quad \forall t \qquad (32)$$

$$\sum_{j\in\{542,543,545\}} E_j \, X_{j,t} \geq \sum_{j\in\{542,543,545\}} BaseComp_j \, D_{i,t} \qquad \forall i \ni M_{i,j} > 0 \quad \forall t \tag{33}$$

$$\sum_{j\in\{547,548,550\}} E_j \, X_{j,t} \geq \sum_{j\in\{547,548,550\}} BaseComp_j \, D_{i,t} \qquad \forall i \ni M_{i,j} > 0 \quad \forall t \tag{34}$$

$$\sum_{j\in\{552,553,555\}} E_j \, X_{j,t} \geq \sum_{j\in\{552,553,555\}} BaseComp_j \, D_{i,t} \qquad \forall i \ni M_{i,j} > 0 \quad \forall t \tag{35}$$

Feedstock constitutes a considerable part of the energy sources that the petrochemicals demand sector consumes. The percentages of these are also preserved as of base year (36).

$$E_j \, X_{j,t} \geq 0.43 \, D_{i,t} \qquad \forall j \in \{566, 570, 574\} \quad \forall i \ni M_{i,j} > 0 \quad \forall t \tag{36}$$

The hydroelectric plant projects cannot be realized before 2 years (37), while nuclear plant can only be built in 7 years (38).

$$OpenHydro_{h,t} = 0 \qquad \forall t \leq 2 \tag{37}$$

$$OpenNuclear_t = 0 \qquad \forall t \leq 7 \tag{38}$$

Additional constraints like policy constraint on the percentage of exports in total resources will be explained in the results and analyses section.

4.5 Model Objective

The objective of the model is to minimize the discounted sum of all

- activity costs
- investment costs,
    - capacity expansion in capacitated arcs
    - capacity expansion in power sector
        - plants with linear investment costs
        - plants with fixed plus linear variable investment costs
        - hydroelectric plant projects
        - nuclear plant project
    - capacity expansion in oil refining
    - capacity expansion in electricity transmission

Note that the activity costs are directly discounted to the base year. However, the investment costs are first annualized along the lifetime of the facility. Then the present value as of year t is found for the portion of the annualized costs which lie in the planning horizon. Finally this value is discounted to the base year.

$$
\begin{aligned}
Min \quad & \sum_{t=2003}^{2020} \left(\frac{1}{1+r} \right)^{t-1} \left[\sum_{j=1}^{650} C_{j,t} \; x_{j,t} \right] \\
+ \quad & \sum_{t=2003}^{2020} \left(\frac{1}{1+r} \right)^{t-1} \left((1+r)^{L_j - T + t} \frac{(1+r)^{T-t} - 1}{(1+r)^{L_j} - 1} \right) \\
& \Bigg[\quad \sum_{j=1}^{650} ArcCapC_j \; CapInv_{j,t} \\
& \quad + \sum_{j=1}^{650} PowCapC_j \; PowInv_{j,t} \\
& \quad + \sum_{j=1}^{650} PowVarC_j \; PowInv_{j,t} \qquad + \sum_{j=1}^{650} PowFixC_j \; OpenPlant_{j,t} \\
& \quad + \sum_{h=1}^{20} HydroCost_h \; OpenHydro_{h,t} \\
& \quad + NuclearCost \; OpenNuclear_t \\
& \quad + \sum_{n=1}^{4} RefCapC \; RefInv^{n}{}_{t} \\
& \quad + CapCInpTrans^{1\leftrightarrow 2} \; TransInv^{1\leftrightarrow 2}{}_{t} + CapCInpTrans^{2\leftrightarrow 3} \; TransInv^{2\leftrightarrow 3}{}_{t} \Bigg]
\end{aligned}
$$

The full write-up of the model in GAMS coding is presented in Appendix E.

CHAPTER 5

RESULTS AND ANALYSES

Upon solving the mentioned model for the base case the following results were obtained. The first thing that one should keep in mind while referring to these results is that these results do not possess predictive capability, that is, they do not present an anticipation of future position, but a position to be attained under the assumptions of the model if the stated objective is pursued and the suggested investment plan is followed. It provides a set of investment decisions, especially in the power sector, a cost based allocation of increasing fuel demand between alternative energy sources and resulting gas emissions from the energy related activities defined in the system. Before going further the let us mention brief technical information on the modeling environment, the model and the solution:

- The model was coded using the General Algebraic Modeling System (GAMS) version 22.4 and is solved using the MIP solver Cplex 10.1.
- The model consisted of 23 variable blocks (no index) which count to a total of individual variables (with indices) of which 540 were binary variables. It consists of 72 equation (constraint) blocks which sum up to 12,181 lines of constraints.
- The solver came up with an optimal solution after 45,071 iterations.

The results are organized similar to Section 3. First results are given from the resource perspective. After that, the results about power sector investment and composition of the generating capacity is presented. It is followed by the demand sectors' consumption structure. Finally resulting emissions are demonstrated. After the base case results, the results of experimental case, where a simple policy constraint is applied to the model, will be presented and discussed.

5.1 Base Case Results

5.1.1 Resource Use

When the base case results are overviewed, the change in the composition of the resource extraction/import bundle is easily noticed. In 2003 crude oil constitutes the 20% of all extracted or imported resources; however this percentage begins to fall down after 2010 reaching 12% in 2020. A similar but consistent decrease is observed in the percentage of lignite. Once at 17% it falls down o 13% and 8% in 2010 and 2020, respectively. The most significant increase is in the percentage of petroleum coke. As it is a considerably cheap resource with a high heating potential, it is preferred and has increased its share from 2% in 2003 to 12% in 2020, although it is consumed by only two of the industries. Natural gas has also showed an increase. However, the shares until 2012 are quite constant at 19% showing that the extraction/import (mostly import of course) follows the increase in overall demand. Between 2013 and 2020, on the other hand, the share goes up to 26%. The share of the renewable resources remains unchanged throughout the planning horizon with an increase in the production of geothermal energy and a decrease in the other renewables most of which is wood & biomass. These situations are illustrated in Figure 5.1. Another important concern is the share of domestic resources in the total resource supply. In the base year the percentage of domestic resources is 33.8%. This percentage constantly declines during the planning periods reaching the lowest at 2019 with 18.2%. As we have not put any policy restriction on imports such a situation is anticipated as our model (models of this sort) are very sensitive to price differences. Figure 5.2 demonstrates how the share of domestic resources in the resource supply evolves.

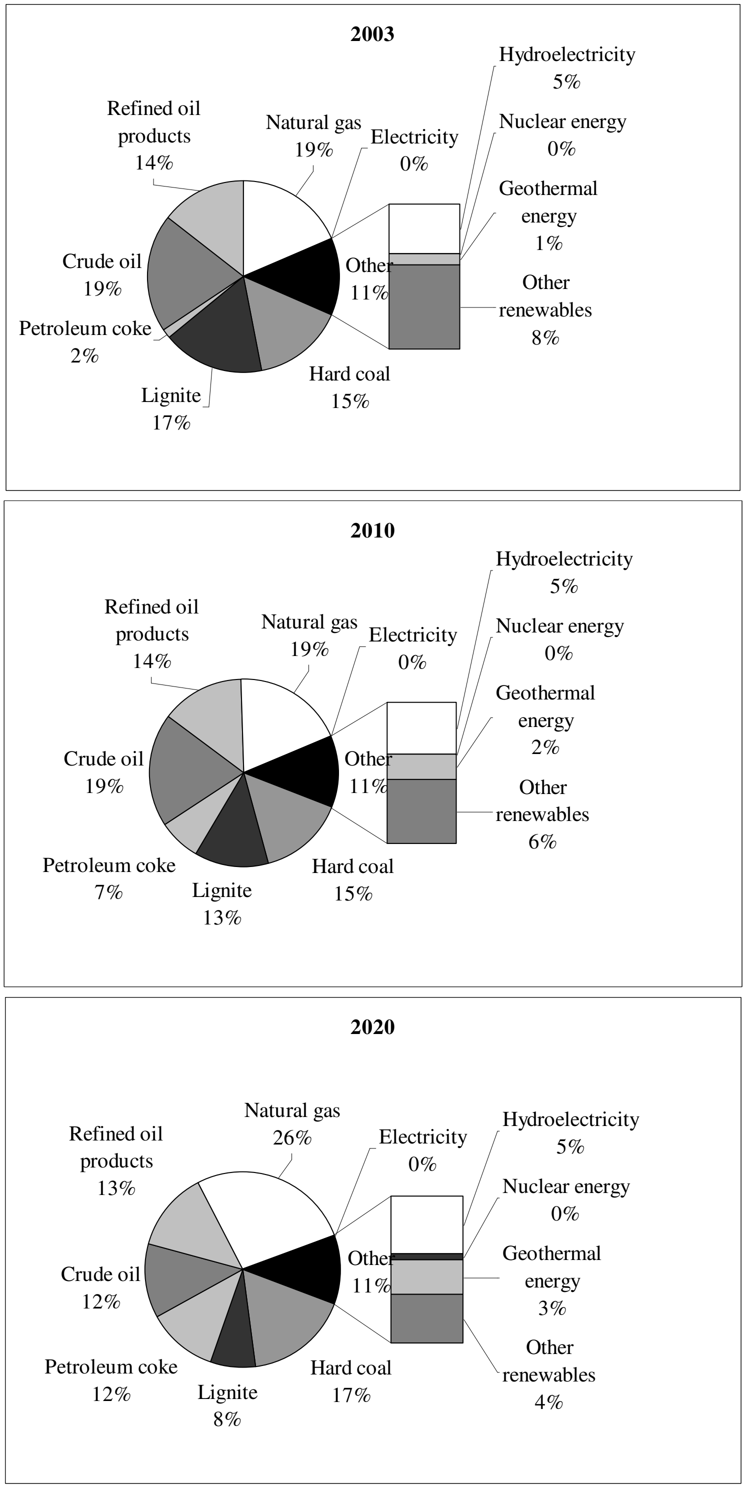


Figure 5.1 Base Case, Composition of Resources

Note that electricity mentioned in the figure is imported electricity. Of course, much more information may be derived from the model considering the resources. Some of them will be presented in the sections of the individual fuels.

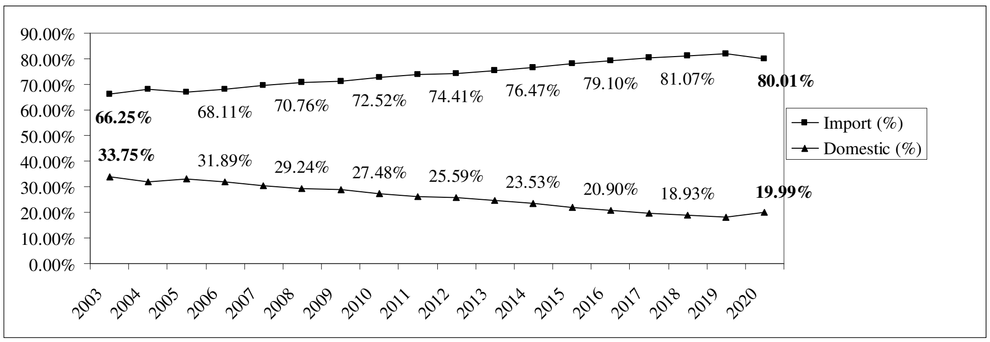


Figure 5.2 Base Case, Imports vs. Domestic Resources

5.1.1.1 Hard Coal

Under this title hard coal and its secondary product, coke is considered. The presentation of model results is reduced to 5 planning periods for convenience. Table 5.1 summarizes the amounts of hard coal and coke that is supplied to the system. Note that the numbers in parentheses show the region to which the resource is imported.

The most significant result is that the results suggest that the domestic hard coal production should be ceased. We previously mentioned that, due to the geological properties of the Zonguldak basin, the extraction is not mechanized but labor intensive, thus expensive. Coal production sector survives as the domestic coal is highly subsidized. As we impose no restriction on the amount of imported coal this result is not surprising. The hard coal import is distributed proportionately to the regional demands as the import to Region 1 satisfies its own consumption, and the rest is supplied by Region 2. Note that this information is not derivable from the table but is observed in the results. Another similar observation is that the imported hard coal is consumed as hard coal, and the consumed coke is imported, not coked in the country. Hard coal import constantly increases as 2020 figure almost triples the base year value of 12 million toe.

Table 5.1 Base Case, Hard Coal Extraction and Import

	2003	**2005**	**2010**	**2015**	**2020**
					unit: M toe
Hard Coal	12.071	12.906	17.806	23.243	35.667
Domestic Hard Coal	0	0	0	0	0
Imported Hard Coal (1)	5.430	5.864	8.191	10.968	16.319
Imported Hard Coal (2)	4.103	4.421	5.874	7.426	12.930
Imported Coke (1)	1.172	1.172	1.516	1.861	2.406
Imported Coke (2)	1.367	1.448	2.226	2.988	4.011

The supplied hard coal is consumed by the sectors in the following amounts. Table 5.2 describes the consumption pattern of the hard coal by the industries. For two industries the demand for hard coal remained unchanged. These are cement industry and other industries. The reason for that is petroleum coke which is cheaper, imported, thus has no restriction on the amount. The use of petroleum coke to satisfy the demand increase in these industries will be presented in the associated section. Comparatively thinking the major use of hard coal is by the other industries and the power generation sector at 2003 but this constantly changes as the amount of hard coal consumed by the iron and steel industry passes it in 2019. Another note is that the consumption of the hard coal firing power plants is not increased until 2017 but demonstrated a sharp increase after that reaching 6.2 million toe by 2020. In 2020 hard coal is mainly consumed by the residential sector which has the 5th rank in the base year.

All of the hard coal is imported, so the domestic hard coal extraction is ceased and all the coke is purchased, the facilities associated with hard coal, coal mines and coking plants remained at their existing capacity.

Table 5.2 Base Case, Hard Coal Use

	2003	2005	2010	2015	2020
					unit: M toe
Residential	0.768	1.440	4.271	7.716	13.463
Industry					
Iron and steel	2.192	2.272	3.374	4.462	6.004
Petrochemicals	0.000	0.025	0.379	0.661	1.159
Cement	0.890	0.890	0.890	0.890	0.890
Sugar	0.085	0.108	0.375	0.644	1.067
Non-Iron Metals	0.061	0.081	0.350	0.618	1.041
Other	5.428	5.428	5.428	5.428	5.428
Power generation	2.498	2.498	2.498	2.498	6.151

5.1.1.2 Lignite

Since all of the lignite is domestically extracted there is no import consideration on it. However the quantities to compare may be the regional outputs of the lignite mines. The lignite in the third region is produced at the base year level. In the second region the production increases in year 2004 and remains at that level. The lignite extracted in the first region increases consistently but with little additions. Consequently the lignite supply increases consistently, at a slow rate. Table 5.3 summarizes these.

Table 5.3 Base Case, Lignite Extraction

	2003	2005	2010	2015	2020
					unit: M toe
Lignite	13.466	14.869	15.186	15.500	15.995
Lignite (1)	11.051	11.079	11.396	11.710	12.205
Lignite (2)	0.000	1.375	1.375	1.375	1.375
Lignite (3)	2.415	2.415	2.415	2.415	2.415

In the base year the major use of lignite is electricity generation by lignite firing power plants (41%). However this state changes as there is no capacity addition to those power plants and becomes 35% in the last year. We see that all the sectors except fertilizer, have kept their lignite consumptions constant during the planning periods. Table 5.4 demonstrates these results.

Table 5.4 Base Case, Lignite Use

	2003	2005	2010	2015	2020
					unit: M toe
Residential	1.241	1.241	1.241	1.241	1.241
Industry					
Petrochemicals	0.010	0.010	0.010	0.010	0.010
Cement	0.487	0.487	0.487	0.487	0.487
Sugar	0.282	0.282	0.282	0.282	0.282
Fertilizer	0.006	0.024	0.228	0.429	0.747
Non-Iron Metals	0.017	0.017	0.017	0.017	0.017
Other	1.372	1.372	1.372	1.372	1.372
Power generation	8.168	9.543	9.543	9.543	9.543

5.1.1.3 Oil and Oil Products

Table 5.5 summarizes the supply of oil and oil products to the energy sector. The supply of crude oil consistently increases and this increase is satisfied by imported crude oil. As the domestic crude oil remains constant the solution offers no change in the oil extraction capacity. The domestic crude oil has a share of 15.7% in 2003 however that falls down to 10% by 2020. Another observation is that the share of domestic refineries in the total supply falls from 56.2% to 45.3% during the planning periods. Table 5.6 presents the refinery outputs and the imported oil products (in parenthesis). On the other hand the total output of the refineries increases from 14.6 to 23.3 million tons, as a result two consecutive expansions are realized in İzmir Refinery increasing the regional refining capacity to 21.2 million tons. Refining capacities of the other two regions remain unchanged. Figure 5.3 illustrates the increase. Other significant observations about the oil products are that jet fuel and other oil are almost totally refined within the country whereas the LPG is totally imported. The consumption of LPG and diesel oil increases; nearly doubling in 17 years.

Table 5.5 Base Case, Oil Extraction and Import

	2003	2005	2010	2015	2020
					unit: M toe
Crude oil	15.932	18.328	23.773	25.691	25.271
Domestic Crude Oil	2.494	2.494	2.494	2.494	2.494
Imported Crude Oil	13.439	15.834	21.279	23.198	22.777
Refined Products (Imported Products)					
Gasoline	0.778	2.249	2.239	1.450	3.151
	(2.417)	(0.945)	(0.955)	(1.744)	(0)
Diesel Oil	5.173	5.974	7.572	8.055	7.932
	(4.808)	(5.418)	(7.734)	(12.906)	(15.741)
Fuel Oil	4.200	3.853	6.037	6.647	4.248
	(0)	(0.353)	(1.460)	(3.354)	(0)
Jet Fuel	0.919	1.061	1.480	1.977	2.043
	(0)	(0)	(0)	(0)	(0.260)
LPG	0	0	0	0	0.271
	(4.112)	(4.815)	(6.888)	(9.335)	(10.804)
Other Oil	3.504	3.678	4.588	5.587	5.647
	(0)	(0)	(0)	(0)	(1.322)

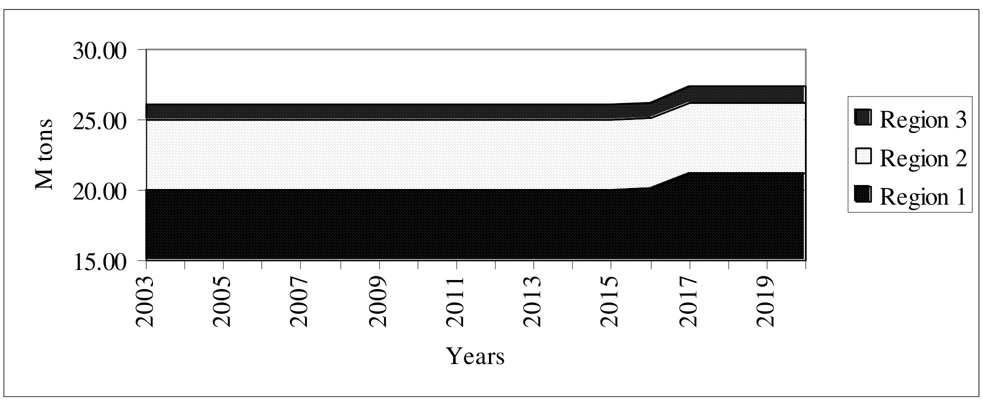


Figure 5.3 Base Case, Refining Capacities by Region

The major consumption area of the oil products is the transportation sector where they are not substitutable. Almost 2/3 of the total oil products are consumed by this sector. Petrochemicals sector uses is mostly as feedstock. A significant increase is observed for the power sector use. In agriculture as diesel is the only fuel option agricultural use constitutes an important portion of the oil products demand. An interesting situation is experienced in power generation sector as the fuel used for electricity generation. The upward movement begins around 2010 and continues rapidly until 2017 making a peak; but then declines and vanishes by 2019.

Table 5.6 Base Case, Oil Products Use

	2003	2005	2010	2015	2020
					unit: M toe
Residential	2.676	2.676	2.676	2.676	2.676
Transportation	12.318	14.207	19.773	26.318	30.788
Industry					
Iron and Steel	0.364	0.364	0.364	0.364	0.364
Petrochemicals	2.155	2.225	2.815	3.480	4.476
Cement	0.054	0.054	0.054	0.054	0.054
Sugar	0.256	0.252	0.252	0.252	0.252
Fertilizer	0.092	0.092	0.092	0.092	0.092
Non-Iron Metals	0.267	0.267	0.267	0.267	0.267
Other	2.628	2.628	2.628	2.628	2.628
Agriculture	2.773	3.131	3.938	4.918	6.112
Non-Energy Uses	2.098	2.201	2.514	2.844	3.219
Power generation	0	0	3.230	6.695	0

5.1.1.4 Natural Gas

The production of natural gas within the country does not increase indicating that there is no capacity added to the initial production capacity. On the other hand we see a rapid increase in the overall production thus the imported natural gas. LNG import is done at capacity and no new capacity to the regasification facilities is added. The supply of natural gas is 14.7 million toe in 2003 which rises up to 55.9 million toe by 2020.

Table 5.7 Base Case, Natural Gas Extraction and Import

	2003	2005	2010	2015	2020
					unit: M toe
Natural Gas	14.749	16.648	23.103	37.268	55.904
Domestic Natural Gas	0.510	0.510	0.510	0.510	0.510
Imported Natural Gas	14.239	10.406	16.860	31.025	49.661
Imported LNG	0	5.733	5.733	5.733	5.733

When the uses of the above production are observed an interesting result is seen. The use of natural gas as a fuel remains constant for the demand sectors. On the other hand the consumption by the power sector increases from 5.9 to 45.8 million toe in the planning periods.

Table 5.8 Base Case, Natural Gas Use

	2003	2005	2010	2015	2020
					unit: M toe
Residential	3.662	3.662	3.662	3.662	3.662
Industry					
Petrochemicals	0.337	0.337	0.337	0.337	0.337
Sugar	0.086	0.086	0.086	0.086	0.086
Fertilizer	0.435	0.435	0.435	0.435	0.435
Non-Iron Metals	0.362	0.362	0.362	0.362	0.362
Other	3.488	3.488	3.488	3.488	3.488
Power generation	5.932	7.774	14.033	27.768	45.840

5.1.1.5 Other Resources

The most significant of the other resources is petroleum coke. We have told that it was a relatively cheap resource with a high heating potential. We see in the results that petroleum coke is preferred to other fuels by the sectors which use it. The import of petroleum coke has increased from 1.4 million toe in 2003 to 24.5 million toe by 2020. This indicates a percentage increase from 2% to 12%. Among all demand sectors only cement industry and other industries consume petroleum coke, and they tend to satisfy all of their attainable consumption with petroleum coke. Among the renewables geothermal heat and solar heat constantly increases their production. Their increases were limited as a model constraint, and we see that they use their existing capacities to the end. The production and import of other resources during the planning horizon is summarized by the Table 5.9 below.

Table 5.9 Base Case, Other Resources Production and Import

	2003	2005	2010	2015	2020
					unit: M toe
Petroleum Coke	1.420	2.228	8.434	14.610	24.358
Geothermal Heat	0.785	1.205	2.430	3.780	5.102
Solar Heat	0.243	0.475	0.883	1.333	1.783
Wood & Biomass	5.765	5.765	5.765	5.765	5.765

5.1.2 Power Sector

In this section we will briefly present the results about the power sector investments. As we already told, the power sector investment was related to the peak load demand forecast. A 15% reserve margin above the peak load is required as the generating capacity in any year. At first glance it is noticed that lignite plants are not preferred in any region despite the abundant resources. Hard coal, on the other hand, is preferred until the end of the planning horizon. In Region 1, the initial capacity is 480 MW. This capacity is increased to 1,198 MW in 2018; similarly Region 2 has existing hard coal power plant(s). The increase is realized in two steps, 903 MW and 909 MW in years 2019 and 2020, respectively. In 2017 Region 3 builds its first hard coal power plant(s) with an 89 MW capacity. Diesel and fuel oil plants are preferred, too, reaching a total capacity of 6,537 MW. The initial capacity is sufficient to satisfy the peak demand condition until 2007. The investments begin after that as the model parameters about maximum investment allow.

Table 5.10 Base Case, Generation Capacities

		2003	2005	2010	2015	2020
						unit: MW
Region 1	Hard coal	480	480	480	480	1,199
	Lignite	4,095	4,095	4,095	4,095	4,095
	Diesel	189	372	772	892	1,017
	Fuel oil	1,456	1,656	2,156	2,636	3,236
	Natural gas	11,148	11,148	11,148	22,410	33,210
	Wind	17	117	367	607	699
	Geothermal	15	115	365	605	756
	Hydro Project	1,201	1,201	1,201	1,694	1,694
	Hydro	184	846	2,346	2,946	5,946
Region Total		18,785	20,031	22,931	36,365	51,851
Region 2	Hard coal	1,320	1,320	1,320	1,320	3,142
	Lignite	979	979	979	979	979
	Diesel	2	39	239	599	1,194
	Fuel oil	477	477	477	597	717
	Natural gas	357	357	357	357	7,557
	Wind	0	0	0	60	240
	Geothermal	0	0	0	60	191
	Hydro Project	2,950	2,950	3,470	4,273	4,273
	Hydro	281	281	1,444	4,444	6,227
	Nuclear	0	0	0	1,500	1,500
Region Total		6,366	6,382	7,502	12,925	22,780
Region 3	Hard coal	0	0	0	0	89
	Lignite	1,831	1,831	1,831	1,831	1,831
	Diesel	44	44	44	44	44
	Fuel oil	569	569	569	569	569
	Natural gas	0	0	0	0	0
	Wind	0	0	0	0	0
	Geothermal	0	0	0	0	0
	Hydro Project	7,733	7,733	11,584	13,021	13,021
	Hydro	230	230	1,067	1,067	1,067
Region Total		10,407	10,745	15,095	16,532	16,621
Country Total		35,558	37,158	45,529	65,823	91,253

The largest group of plants is the natural gas fired power plants. They constitute 44.6 % of the total installed capacity. The model does not suggest any investment until 2011. But after that, for instance in Region 1, an average of 2,450 MW capacity is added annually. Clean technologies like wind farms and geothermal plants are preferred and built in Region 1. As the observed potential of Turkey for developing such plants was not very large so the artificial constraints on their maximum investments determine their investments. The hydroelectric potential is utilized, too. The small hydroelectric power plants have an aggregated capacity of 8,514 MW which indicates a capacity 12 times larger than the initial one.

In the model we have modeled 21 plants as projects. The model suggests that the nuclear plant in Region 1 is opened in 2011. Similarly all hydroelectric power plant projects are realized. Table 5.11 gives the opening schedule for the hydroelectric power plant projects.

Table 5.11 Base Case, Hydroelectric Power Plant Projects

Plant	Year	Plant	Year	Plant	Year	Plant	Year
Ilısu	2005	**Çetin**	2007	**Kayraktepe**	2011	**Cizre**	2012
Yusufeli	2008	**Artvin**	2006	**Güresöğüt**	2011	**Arkun**	2013
Boyabat	2010	**Beyhanı**	2010	**Göktaş**	2008	**Alkumru**	2013
Doğanlı	2005	**Kandil En.**	2007	**Yedigöze**	2006	**Kargı**	2014
Uzungöl	2009	**Kaleköy**	2009	**Çukurca**	2012	**Hakkari**	2014

5.1.3 Demand Sectors

In this section we will present the demand sectors' fuel compositions. We have previously given the consumption quantities of the fuels in the resources section. Now we will compare with figures the sectoral change in the consumption bundle. As individual industries mainly focus on one available resource the industrial sector will be given in aggregate terms. Since for non-energy uses there are no competing fuels, and the quantity relation between diesel oil and electricity is already determined, they will be excluded.

5.1.3.1 Residential Sector

The residential sector is consuming mostly wood & biomass at the beginning of the planning horizon. Natural gas and lignite is used for cooking and space heating. LPG is used for mostly cooking and water heating. These five are the top ranked fuels by consumption. At the end, the share of wood and biomass falls down to 11% as the base year amount was the annual reserve for that. Natural gas declines to 7%, and lignite to 2% and it is no more ranked in the top five energy sources. Their share is taken by geothermal heating; it is cheap and is a considerable resource for Turkey, and hard coal whose importing costs are remarkably lower than domestic production. Figure 5.4 and 5.5 show the consumption bundles as of 2003 and 2020, respectively.

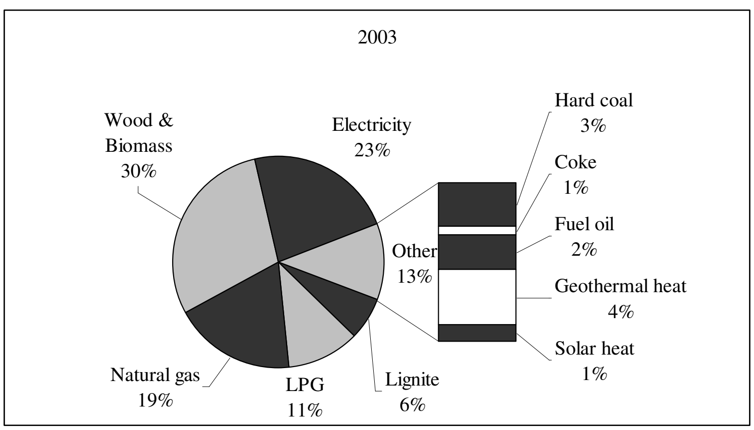


Figure 5.4 Base Case, Residential Sector Consumption Bundle 2003

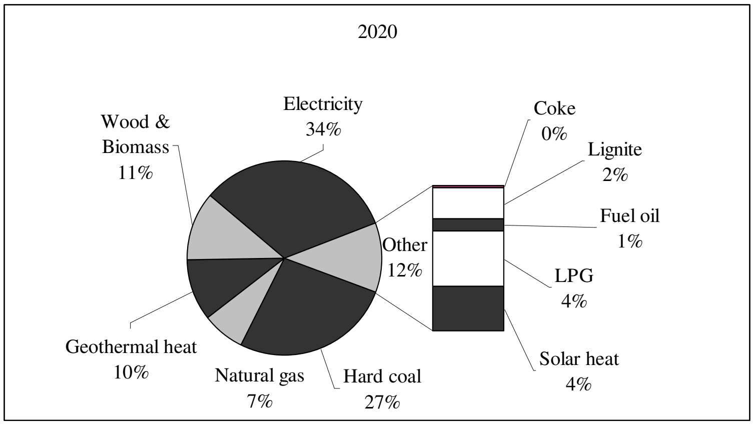


Figure 5.5 Base Case, Residential Sector Consumption Bundle 2020

5.1.3.2 Transportation Sector

The transportation sector is the main consumer of oil products. As of 2003 diesel, which we took as the representative of freight and passenger transportation, has the largest share. Since we assumed that the transportation type it resembles will at least have the same percentage in the future it would not be less than 54%, the base year share. Similar constraint was for kerosene, which we have named as jet fuel up to now. Diesel oil, LPG and gasoline were assumed to compete for personal transportation. As a result of this, according to the model results LPG captures the position of gasoline for this type of transportation. Figure 5.6 demonstrates the change in composition between 2003 and 2020.

5.1.3.3 Industry Sector

The most important fuel for the industrial sector is natural gas as of 2003. However the market share of natural gas, and hard coal and fuel oil as well, is taken by petroleum coke. Petroleum coke, which once has a share around 5% of the total industry demand, increases its share to 32% and becomes the dominant fuel in the sector (Figure 5.7).

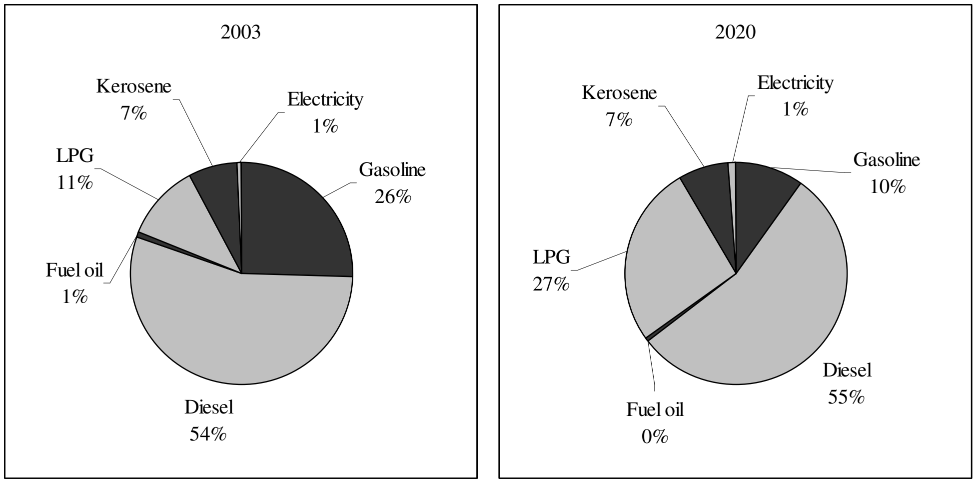


Figure 5.6 Base Case, Transportation Sector Consumption Bundle, 2003 vs. 2020

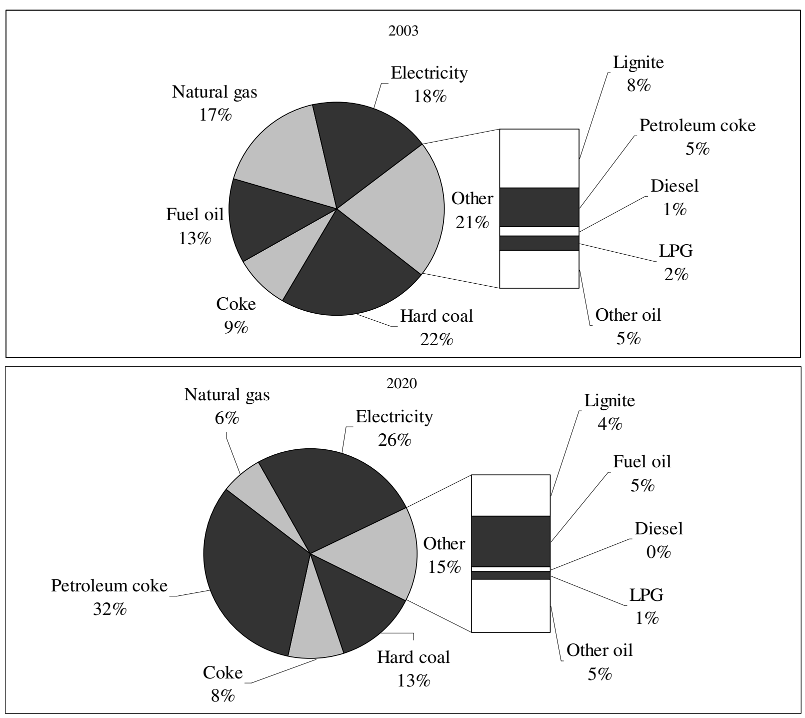


Figure 5.7 Base Case, Industry Sector Consumption Bundle, 2003 vs. 2020

5.1.4 Emissions

According to the investment and resource selection plan offered by the model, the CO_2 emissions are expected to increase constantly with the increasing energy consumption. Base year it is calculated as 229 million tons and it increases up to 582 million tons in 2020 with an annual increase about 20 millions annually. Figure 5.8 below demonstrates the increase in CO_2 emissions calculated.

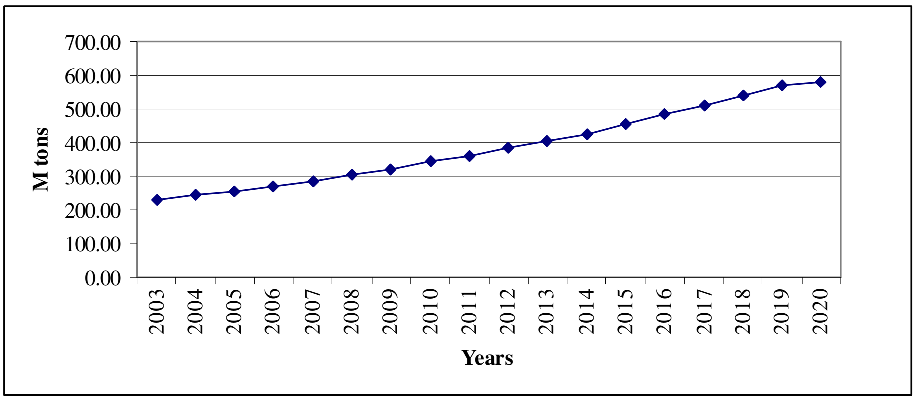
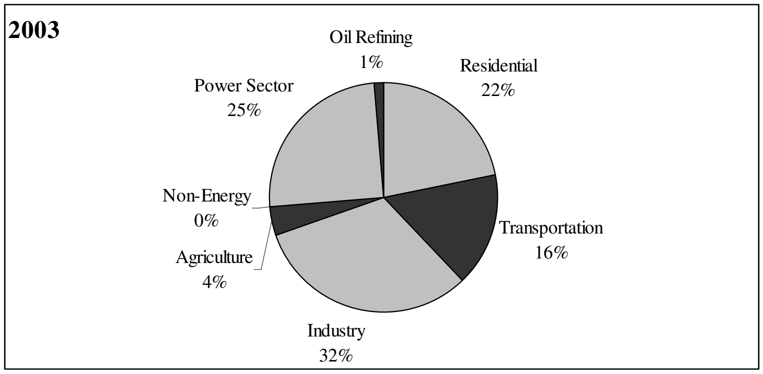


Figure 5.8 Base Case, CO_2 Emissions

The major source of CO_2 emissions in the base year is the industry sector with a share of 32% in total emissions. It is followed by power sector (25%) and residential sector (22%), respectively. In 2020 these shares change slightly, without changing the order. Industrial sector (35%) and power sector (29%) increases their shares whereas the share of residential sector decreases to 17%. Figure 5.9 below illustrates the change in shares.



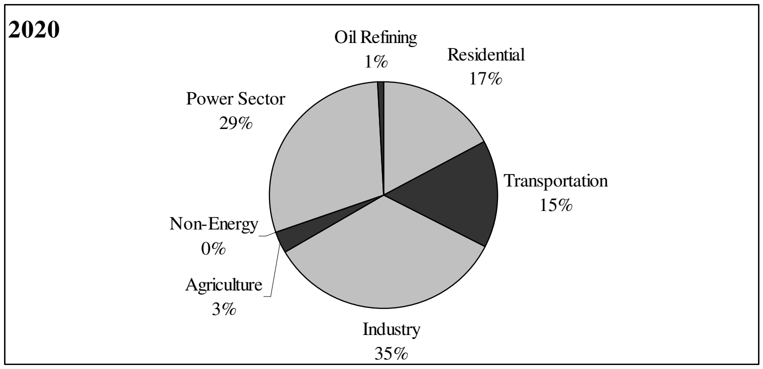


Figure 5.9 Base Case, Sources of CO2 Emissions

5.2 Policy Case: Domestic vs. Import

In this section we are going to add the model a simple constraint that is capable of representing a serious policy objective. The policy objective can be stated as "*Beginning with 2014, the share of domestic resources in the total supply will at least be 50%"*. The selection of 2014 is quite arbitrary; the policy constraint will be active in the last 1/3 of the planning horizon. We define two new sets, *Domestic(J)* and *Import(J)* which are set of arcs denoting resource extractions within the country and importing energy resources, respectively. The constraint below (39) is added and the modified problem is solved again. The solution will be presented in the same order as before and differences will be discussed.

$$\sum_{j \in \mathrm{Domestic(J)}} E_j X_{j,t} \geq \sum_{j \in \mathrm{Import(J)}} E_j X_{j,t} \qquad \forall j \in \mathrm{Domestic(J)} \cup \mathrm{Import(J)} \quad \forall t \geq 2012 \qquad (39)$$

5.2.1 Resource Use

If we put the resource supplies in both problems together we obtain the following table, Table 5.12. We see that introduction of a policy restriction on the share of domestic resources results in change of the supply pattern. In the table base case supply for the same resource-year pair is provided in parentheses. The most significant change occurs between the supply of hard coal and petroleum coke. Hard coal was totally imported in the base case; now this pattern has to change in favor of domestic hard coal, as it replaces petroleum coke a product with no domestic production. The differences between other resources are not as significant as these. But of course speaking in totals does not show the difference between the domestic and foreign goods, which we will discuss in resource sections. The other significant changes are increase in the extraction of lignite after 2014, decrease in the natural gas supply after 2015, a sharp decrease in crude oil supply after the policy deadline which then compensated until 2020, a change in the opposite direction for refined product import, and finally, increased supply of renewable resources. Figure 5.10 compares the shares of different resources in the total supply as of 2020. Note the change in natural gas, petroleum coke, lignite and hard coal which are shown with arrows.

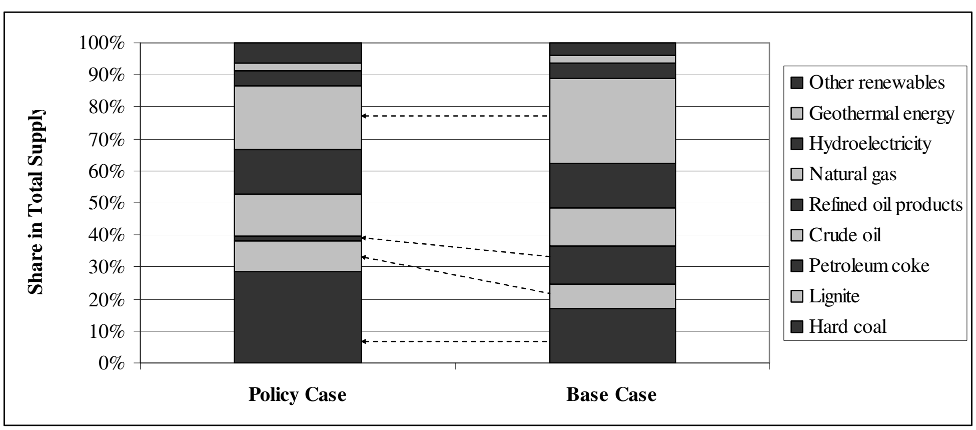


Figure 5.10 Changes in Shares between the Base Case and Policy Case, 2020

Table 5.12 Changes in Resource Supply between Base Case and Policy Case

	2003	2005	2010	2015	2020
Hard coal	12.078	13.538	22.795	30.067	60.492
	(12.071)	(12.906)	(17.806)	(23.243)	(35.667)
Lignite	13.466	14.837	14.837	18.124	20.284
	(13.466)	(14.869)	(14.186)	(15.500)	(15.995)
Petroleum coke	1.412	1.412	1.412	1.412	3.769
	(1.42)	(2.228)	(8.434)	(14.61)	(24.358)
Crude oil	15.909	18.309	23.863	10.591	17.683
	(15.932)	(18.328)	(23.773)	(25.691)	(25.271)
Oil products	11.343	11.631	21.122	37.192	38.795
	(11.337)	(11.531)	(17.038)	(27.34)	(28.127)
Natural gas	14.751	16.647	23.102	37.185	41.958
	(14.749)	(16.648)	(23.103)	(37.268)	(55.904)
Electricity	0	0	0	0	0
	(0)	(0)	(0)	(0)	(0)
Hydroelectricity	3.580	3.580	4.909	7.220	9.405
	(3.58)	(3.58)	(5.528)	(5.845)	(9.405)
Nuclear energy	0	0	0	1.017	1.017
	(0)	(0)	(0)	(1.017)	(1.017)
Geothermal en.	0.793	1.265	2.622	4.131	5.611
	(0.793)	(1.265)	(2.622)	(4.131)	(5.611)
Other renew's	6.008	6.370	7.223	10.681	13.229
	(6.008)	(6.275)	(6.758)	(7.299)	(7.839)

5.2.1.1 Hard Coal

In the base case domestic supply of hard coal was not preferred. In the policy case the share in total supply of hard coal is 95%. In 2020, 57.1 Mtoe hard coal is extracted reaching it maximum. The increase in total hard coal supply is 25 Mtoe for 2020 and the import of hard coal almost diminished. Only coke is imported to satisfy the existing demand and the demand of iron and steel industry. As the domestic hard coal supply is so high that it did not only replace the imported hard coal but other (petroleum coke) imported resources as well. Considering the initial capacity of the domestic hard coal production was 4.75 million tons (3.09 M toe) this requires a large capacity expansion in hard coal mining. Since no maxima were defined for the upper limit of capacity increases other than an annual limitation, the capacity of hard coal extraction reaches this unattainable level. The capacity expansion begins long before the policy deadline as a result of the annual limit and a total of 54 Mtoe of new capacity is added. And it is interesting that the newly added capacity is not utilized until 2014. Table 5.13 below summarizes the extraction and import of hard coal and the extraction capacity for domestic hard coal.

Table 5.13 Policy Case, Hard Coal Extraction, Import and Capacity

	2003	2005	2010	2015	2020
					unit: M toe
Hard Coal	12.078	13.538	22.795	30.067	60.492
Domestic Hard Coal	0	0	0	27.528	57.083
Imported Hard Coal (1)	5.435	6.481	13.095	0	0
Imported Hard Coal (2)	4.104	4.518	7.161	0	0
Imported Coke (1)	1.172	1.172	1.172	1.172	1.635
Imported Coke (2)	1.366	1.366	1.366	1.366	1.773
Capacity	3.71	5.34	13.3	33.0	57.1

Table 5.14 below summarizes the use of hard coal in the demand sectors. Residential sector experiences a decrease in the hard coal it consumes, which is around 3 Mtoe in 2020. Similarly iron and steel industry uses less hard coal (hard coal + coke). Cement industry and the other industries increase their hard coal consumption considerably. Hard coal was not preferred by these industries in the base case, now it replaces petroleum coke. Another striking increase is observed in power sector.

Table 5.14 Policy Case, Hard Coal Use

	2003	2005	2010	2015	2020
					unit: M toe
Residential	0.768	1.345	3.458	5.053	10.296
Industry					
Iron and steel	2.192	2.192	2.192	2.192	3.048
Petrochemicals	0.000	0.025	0.377	0.661	1.159
Cement	0.891	0.967	1.883	2.802	3.919
Sugar	0.085	0.108	0.375	0.644	1.067
Non-Iron Metals	0.061	0.081	0.350	0.618	1.041
Other	5.434	6.151	11.353	16.522	22.691
Power generation	2.498	2.498	2.498	1.058	16.424

5.2.1.2 Lignite

Lignite extraction increases in the policy case. The increase between the two cases as of 2020 is 5 Mtoe. The total amount of lignite extracted increases 25 Mtoe from 273 to 298 Mtoe. When regionally viewed, the lignite extractions in Region 3 did not change, Region 1 slightly increases and Region 2 considerably increased. The extraction capacity did not increase in regions 1 and 3, however the capacity of Region 2 facilities increased 3.62 Mtoe (14.48 Mton) until 2020. Table 5.15 presents these results.

Table 5.15 Policy Case, Lignite Extraction

	2003	2005	2010	2015	2020
					unit: M toe
Lignite	13.466	14.837	14.837	18.124	20.284
Lignite (1)	11.051	11.047	11.047	12.743	12.743
Lignite (2)	0.000	1.375	1.375	2.966	5.126
Lignite (3)	2.415	2.415	2.415	2.415	2.415
Capacity	16.663	16.663	16.663	18.124	20.284

In the base year the major use of lignite was in electricity generation. This situation continues in the policy case. When the results tabulated in Table 5.16 are analyzed, we see that the consumption of lignite in the residential sector and most of the industries did not change; and decreased in fertilizer industry. That indicates the increase in lignite extraction is to supply fuel for the power plants. Consequently wee see an increase in the size of the aggregated lignite plants in Region 2.

5.2.1.3 Oil and Oil Products

The supply of oil and oil products does not alter much as these are mostly used in the transportation sector and in that sector they are not substitutable. If we look at the results on Table 5.17 we see that the domestic extraction of crude oil has increased, moreover the domestic reserves were depleted at the end of 2018. We also see that on the amount of oil products refined in Turkey. From 22 Mtoe in 2010 it falls down to 1.6 Mtoe in 2010 as there is no more oil to be extracted. The crude oil is mostly replaced by the refined oil products. Since the constraint is on the total amount of supply to the energy sector not to the demand sectors, refining is not preferred as it causes loss due to thermal efficiency of the process, although it is cheaper for some products to refine in Turkey. The refining capacity increases this time in Region 3 to satisfy the increase in domestic crude oil production. Refining capacity has increased to it peak value, 32.2 Mtoe, in 2014.

Table 5.16 Policy Case, Lignite Use

	2003	2005	2010	2015	2020
					unit: M toe
Residential	1.241	1.241	1.241	1.241	1.241
Industry					
Petrochemicals	0.010	0.010	0.010	0.010	0.010
Cement	0.487	0.487	0.487	0.487	0.487
Sugar	0.282	0.280	0.280	0.280	0.280
Fertilizer	0.006	0.006	0.006	0.006	0.009
Non-Iron Metals	0.017	0.017	0.017	0.017	0.017
Other	1.372	1.372	1.372	1.372	1.372
Power generation	8.168	9.543	9.543	13.693	15.781

Table 5.17 Policy Case, Oil Extraction and Import

	2003	2005	2010	2015	2020
					unit: M toe
Crude oil	15.909	18.309	23.863	10.591	17.683
Domestic Crude Oil	0.000	0.000	0.000	10.591	0.000
Imported Crude Oil	15.909	18.309	23.863	0	17.683
Oil Products					
Domestic Refining	14.567	16.820	22.024	9.828	16.234
Import	11.343	11.631	21.122	37.192	38.795

The use of oil products by the sectors did not change much compared to the base case. Only significant changes are, the shit from coke to fuel oil in iron and steel industry, and the decrease in power sector use, as diesel oil and fuel oil are only consumed between 2009 and 2013. Table 5.18 summarizes these results.

Table 5.18 Policy Case, Oil Products Use

	2003	2005	2010	2015	2020
					unit: M toe
Residential	2.676	2.676	2.676	2.676	2.676
Transportation	12.319	14.207	19.773	26.318	30.783
Industry					
Iron and Steel	0.364	0.444	1.547	2.635	3.303
Petrochemicals	2.155	2.225	2.817	3.480	4.476
Cement	0.054	0.054	0.054	0.054	0.054
Sugar	0.256	0.256	0.256	0.256	0.256
Fertilizer	0.092	0.110	0.313	0.515	0.755
Non-Iron Metals	0.267	0.267	0.267	0.267	0.267
Other	2.628	2.628	2.628	2.628	2.628
Agriculture	2.773	3.131	3.938	4.918	6.112
Non-Energy Uses	2.098	2.201	2.514	2.844	3.219
Power generation	0	0	6.028	0	0

5.2.1.4 Natural Gas

The supply of natural gas in the policy case is significantly less than the base case supply, although it is still consistently increasing. Domestic natural gas and the imported LNG remain at their previous levels, so this decrease in the imported natural gas. No new capacity is added to the natural gas facilities. When we look at the use of natural gas in the sectors, we see little or no change in the demand sectors, with an increase in fertilizer industry. Therefore it is obvious that the high level of investments in natural gas power plants is not the situation in this case. The supply of natural gas is presented in Table 5.19 and the use of natural gas is presented in Table 5.20.

Table 5.19 Policy Case, Natural Gas Extraction and Import

	2003	2005	2010	2015	2020
					unit: M toe
Natural Gas	14.751	16.647	23.102	37.185	41.958
Domestic Natural Gas	0.510	0.510	0.102	0.510	0.510
Imported Natural Gas	14.241	10.405	17.267	30.942	35.715
Imported LNG	0.000	5.733	5.733	5.733	5.733

Table 5.20 Policy Case, Natural Gas Use

	2003	2005	2010	2015	2020
					unit: M toe
Residential	3.662	3.662	3.662	3.662	3.662
Industry					
Petrochemicals	0.337	0.337	0.337	0.337	0.337
Sugar	0.086	0.085	0.085	0.085	0.085
Fertilizer	0.435	0.435	0.435	0.435	0.510
Non-Iron Metals	0.362	0.362	0.362	0.362	0.362
Other	3.488	3.488	3.488	3.488	3.488
Power generation	5.934	7.774	14.032	27.689	32.243

5.2.1.5 Other Resources

The most significant of the other resources is again petroleum coke. As it is a resource that is completely imported, it loses its dominant market position under this policy. The use of geothermal and solar does not change as they are already at the defined limits. Another deviation from base case results is observed in wood & biomass which double their consumption in the second half of the planning horizon. Table 5.21 summarizes these results.

Table 5.21 Policy Case, Other Resources Production and Import

	2003	2005	2010	2015	2020
					unit: M toe
Petroleum Coke	1.412	1.412	1.412	1.412	3.769
Geothermal Heat	0.785	1.205	2.430	3.780	5.102
Solar Heat	0.243	0.475	0.883	1.333	1.783
Wood & Biomass	5.765	5.859	6.229	9.147	11.155

5.2.2 Power Sector

Hard coal has dominated the power sector, too. In the base case the hard coal plants in Region 1 had a capacity of 1,199 MW in 2020; this value has increased to 10,651 MW in the policy case. Aggregated lignite plants also increased in size beginning in 2012. Their total capacity has reached 7,700 MW in Region 1 and 3,533 MW in Region 2 and remained the same in Region 3, this is 89% more compared to the base case capacity Since these capacities accumulate in the first two regions, the small hydroelectric plants there decreased compared to the base case. Subsequently the investments on small hydroelectric plants increased in Region 3. All large hydroelectric power plants are built as well and the nuclear plant is opened in 2010. The Figure 5.11 below demonstrates the change in the shares of energy resources as of 2020, between the base case and the policy case, by regions and the total capacity.

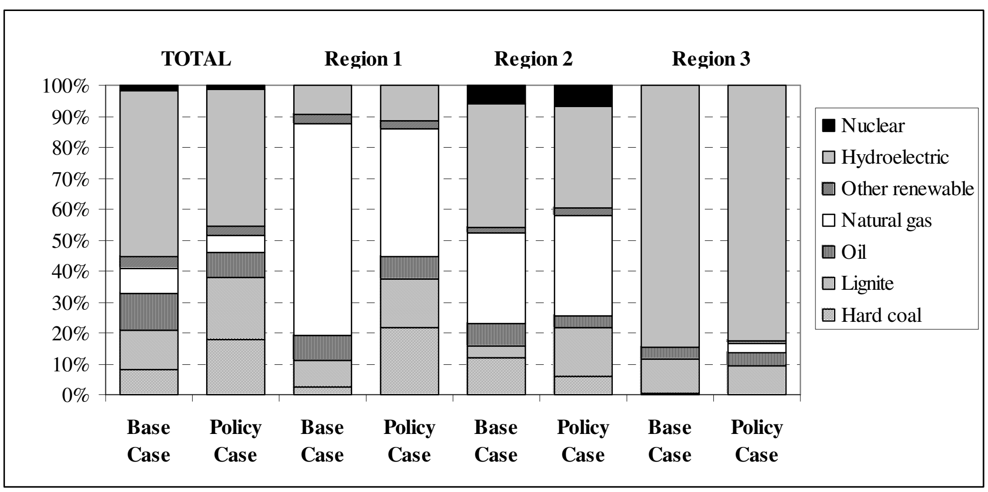


Figure 5.11 Shares by Energy Resources

Table 5.22 Base Case, Generation Capacities

		2003	2005	2010	2015	2020
						unit: MW
Region 1	**Hard coal**	480	480	480	3,315	10,515
	Lignite	4,095	4,095	4,095	7,628	7,628
	Diesel	189	389	889	1,009	1,369
	Fuel oil	1,456	1,656	2,156	2,276	2,580
	Natural gas	11,148	11,148	11,148	19,851	20,709
	Wind	17	117	367	547	607
	Geothermal	15	115	365	526	586
	Hydro Project	1,201	1,201	1,201	1,694	1,694
	Hydro	184	924	986	986	3,986
Region Total		20,788	22,130	23,697	39,846	51,693
Region 2	**Hard coal**	1,320	1,320	1,320	1,320	1,320
	Lignite	979	979	978	2,045	3,533
	Diesel	2	2	2	122	122
	Fuel oil	477	477	477	597	717
	Natural gas	357	357	357	3,029	7,253
	Wind	0	0	0	153	273
	Geothermal	0	0	0	120	240
	Hydro Project	2,950	2,950	3,733	4,273	4,273
	Hydro	281	781	2,281	3,064	3,064
	Nuclear	0	0	0	1,500	1,500
Region Total		6,366	6,366	8,587	15,952	22,061
Region 3	**Hard coal**	0	0	0	0	0
	Lignite	1,831	1,831	1,831	1,831	1,831
	Diesel	44	44	44	44	164
	Fuel oil	569	569	569	569	689
	Natural gas	0	0	0	0	554
	Wind	0	0	0	0	60
	Geothermal	0	0	0	0	111
	Hydro Project	7,733	7,733	11,451	13,021	13,021
	Hydro	230	730	1,446	3,246	3,246
Region Total		10,407	10,667	15,385	18,755	19,518
Country Total		37,561	39,163	47,669	74,553	93,273

5.2.3 Demand Sectors

In this section we will again compare the base case results and the policy case results with figures. For each demand sector the consumption bundle for 2020 is compared for both cases.

5.2.3.1 Residential Sector

In the residential sector shift occurred between wood & biomass and hard coal. As we have seen hard coal has become essential in the power sector but did not show the same importance in demand sectors. For the base case, in 2020, the wood & biomass's share in the consumption bundle was around 11% and it has increased to 21% in the policy case. On the other hand hard coal, once at 27% in total consumption, reduced to 19%. Other sources' shares remained unchanged. Figure 5.12 demonstrates this.

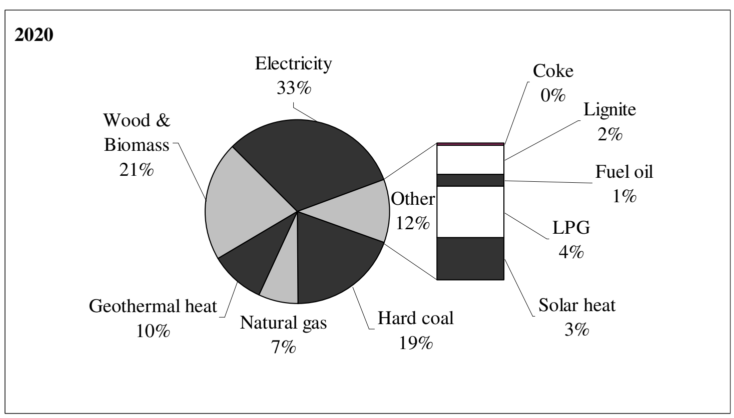


Figure 5.12 Policy Case, Residential Sector Consumption Bundle 2020

5.2.3.2 Transportation Sector

There is no change in transportation sector except for the light shift of 1% from LPG to gasoline. Figure 5.13 demonstrates this.

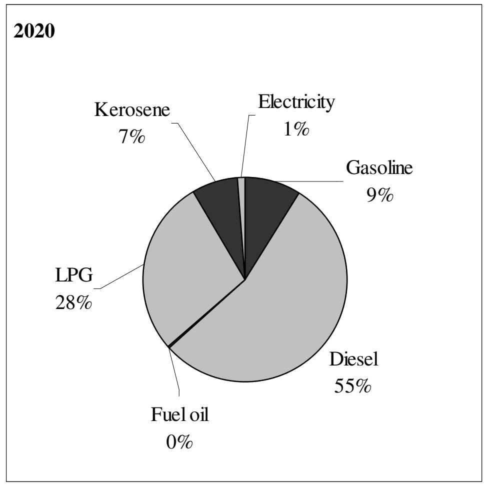


Figure 5.13 Policy Case, Transportation Sector Consumption Bundle 2020

5.2.3.3 Industry Sector

The change in industry sector is from petroleum coke and coke towards hard coal and fuel. We have seen that hard coal took the place of petroleum coke in cement industry and other industries. Coke has left its place to fuel oil in the iron and steel industry. In the final composition hard coal constitutes the 40% of industry consumption; fuel oil, similarly, has reached 10% under the policy. Figure 5.14 illustrates the situation for the policy case.

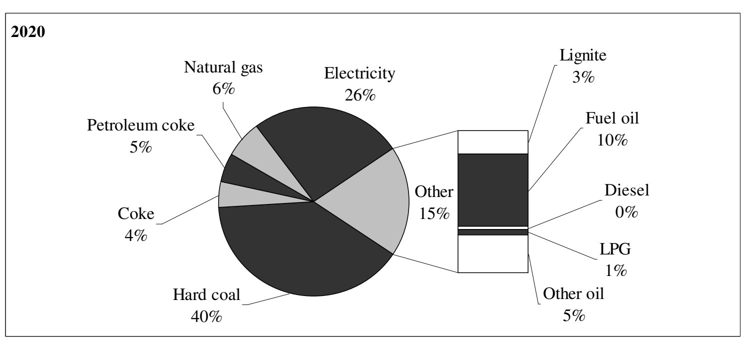


Figure 5.14 Policy Case, Industry Sector Consumption Bundle 2020

5.2.4 Emissions

Finally, the emissions change between the cases. For most of the plan, the emissions go in line with each other. But the increased use of domestic resources causes the ending level of CO2 emission to be larger (about 618 Mtons) for the policy case. The sources of emission change in an anticipated way and with the use of hard coal and lignite instead of natural gas, the emissions originating from power generation increase their share to 32% from 29%. Figure 5.15 shows the emission of CO_2 through the planning periods, and Figure 5.16 shows the sector-wise percentages for the CO_2 emissions.

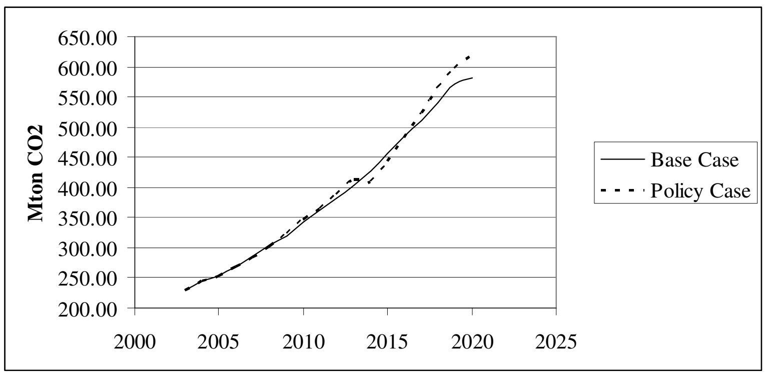


Figure 5.15 CO_2 Emissions of Both Cases

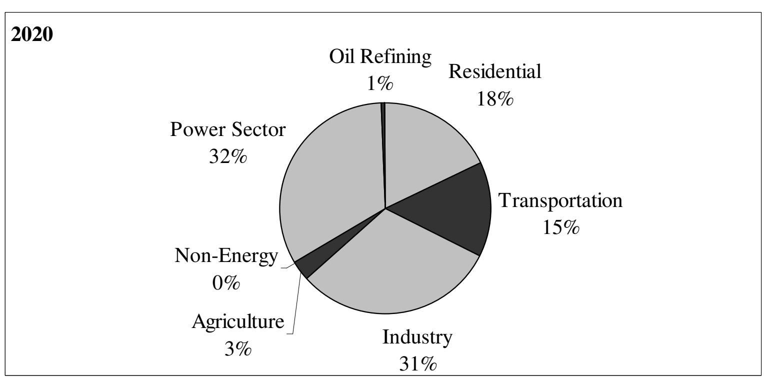


Figure 5.16 Policy Case, CO_2 Emissions

CHAPTER 6

CONCLUSIONS AND FURTHER RESEARCH

Our study addressed a critical issue, energy planning. We focused on the physical structure of the energy system and developed a network model also known as reference energy system for the national energy sector. Our interest was limited to providing a country specific model which aids decision making in resource allocation and investments and aims at minimizing the energy cost for the national economy. Our model comprised a time span of 18 years between 2003 and 2020, which can be considered as a middle term planning horizon for energy models. The model was coded with a mixed integer programming formulation, where a number of linear conversion technologies and power plant projects are tailored into an energy network basis of flow conservation and thermal efficiency. Economic and technologic parameters are determined along with projections of energy, electricity and load demand. The purpose was, as stated, minimizing the system costs. We have provided information on the basic outcome of the model and exercised it under further restrictions of a policy objective. The analysis of results demonstrated that the primary aim of the study ended in success, nevertheless revealing some already known and anticipated limitations of the modeling approach. We will briefly discuss these limitations, which will simultaneously lead us to possible future research areas about the topic.

An obvious limitation was the high level of exogenization in the model. The demand and the prices of the commodities were not defined with an economic rationale. The demand structure that is embedded in the model was not price responsive, whereas in real world the demand for a commodity (including energy) is a function of price, thus changes in accordance with it. On the other hand, our model accepted the demands given. Therefore at this point, a probable future research topic may be constructing the model so that demand and supply are related to the cost (price) of the commodities. Relating the demand of the fuel to the cost of it would require nonlinear programming. Recalling ETA, a nonlinear formulation is required. Such a formulation will help in better representation of conversion technologies and activity costs, too. We have previously mentioned that certain models seek partial equilibrium through iterative solution procedures. Without the need for a non-linear formulation we may iteratively find the demand and supply quantities by solving the problem for the objective and another econometrically defined demand function.

The model separates electricity demand from fuel demand viewing them as imperfect substitutes. On the other hand every fuel may take the place of other freely, that is they are perfect substitutes. Neither of these is true except for some specific uses like lighting, which requires nothing but electricity (at least at this century). The interrelation of prices and demand sectors' preferences on them may be modeled using the economic rationale of substitution.

Another issue is to add the model some macro formulation. Current model is formulated to come up with a mixture of energy resources to satisfy some predetermined demands. However the interaction of the energy system with the overall economy and also the economic development are not taken into account. Considering energy as an input like labor and capital to the manufacturing industries may turn the model into a consumption (production and economic growth) maximizing one. Recall the MACRO modules for ETA and MARKAL.

To sum up, the developed model disregarded the interaction of the energy system with the entire economy, a more sophisticated competition rationale for energy resources and the relation of demand with prices. Future research should address these just in the way the energy models have developed.

To conclude, we must see that use of models for policy building and analysis purposes is a necessity for Turkey. After the initial steps taken in late 70's, energy modeling was put aside. Currently the country is facing numerous questions. We became heavily dependent on natural gas in both residential heating and electricity generation, but there is almost a single supplier of the fuel which is a threat to supply security. We have to adopt some policies regarding gas emissions, but we have to cope with compounding energy demand. We are on the edge of facing a power crisis, but do not know whether to invest in more natural gas plants, realize the hydroelectric plant projects, built a nuclear plant... All these vital questions have turned into subjects of daily political speech, but not more. Politics is undeniably a part of such processes but I strongly believe that we need science to assist us in these decisions and we need it immediately.

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APPENDICES

Appendix A: Conversion Factors

Table A.1 Conversion Factors for Energy (source: [49])

To:	**TeraJoules** *(TJ)*	**GigaCalories** *(Gcal)*	**Million tons of oil equivalent** *(Mtoe)*	**Million British Thermal Units** *(MBtu)*	**Gigawatt-hours** *(GWh)*
From:	*multiply by:*				
TJ	1	238.8	2.388×10^{-5}	947.8	0.2778
Gcal	4.1868×10^{-3}	1	10^{-7}	3.968	1.163×10^{-3}
Mtoe	4.1868×10^{-4}	10^{7}	1	3.968×10^{7}	11630
MBtu	1.9551×10^{-3}	0.252	2.52×10^{-8}	1	2.931×10^{-4}
GWh	3.6	860	8.6×10^{-5}	3412	1

Table A.2 Conversion Factors from Mass and Volume to Heat

Fuel	**Gross Calorific Content**	**Fuel**	**Gross Calorific Content**
Unit: kcal/kg		Hard coal	6,500
Crude oil	10,500	Coke	7,000
Gasoline	10,700	Lignite 1 & 2	2,500
Diesel	10,350	Lignite 3	1,100
Fuel oil	9,600	Pet-coke	7,700
LPG	11,300	Wood &Biomass	2,800
Jet fuel	10,650	*Unit: kcal/m3*	
Other oil	9,600	Natural gas	9,100

Note: 1, 2, 3 after lignite denotes the region where the lignite is extracted.

Appendix B: Description of Network Nodes and Arcs

Table B.1 Description of Network Nodes

Node	Description	Entering Arcs	Leaving Arcs
N001	Foreign coke		A001
N002	Foreign hard coal		A002
N003	Hard coal in the mine in region 1		A003
N004	Extracted hard coal in region 1	A003	A004
N005	Coal in region 1	A002, A004	A005, A009, A010, A011, A140, A156, A172, A257, A270, A283, A296, A312, A328, A344, A352, A364, A400, A412, A424, A436, A455, A474
N006	Coke in region 1	A001, A005	A142, A158, A174, A239, A245, A251, A349, A357, A369, A405, A417, A429, A441, A460, A479
N007	Foreign coke		A006
N008	Foreign hard coal		A007
N009	Coal in region 2	A007	A008, A012, A013, A014, A141, A157, A173, A258, A271, A284, A297, A313, A329, A345, A353, A365, A401, A413, A425, A437, A456, A475
N010	Coke in region 2	A006, A008	A143, A159, A175, A240, A246, A252, A350, A358, A370, A406, A418, A430, A442, A461, A480
N011	Lignite in the mine in region 1		A015
N012	Lignite in the mine in region 2		A016
N013	Lignite in the mine in region 3		A017
N014	Extracted lignite in region 1	A015	A018, A021
N015	Extracted lignite in region 2	A016	A019, A022
N016	Extracted lignite in region 3	A017	A020, A023
N017	Washed lignite in region 1	A018	A144, A160, A176, A259, A272, A285, A298, A314, A330, A346, A354, A366, A376, A384, A392, A402, A414, A426, A438, A457, A476
N018	Washed lignite in region 2	A019	A145, A161, A177, A260, A273, A286, A299, A315, A331, A347, A355, A367, A377, A385, A393, A403, A415, A427, A439, A458, A477

Table B.1 (continued)

Node	Description	Entering Arcs	Leaving Arcs
N019	Washed lignite in region 3	A020	A146, A162, A178, A261, A274, A287, A300, A316, A332, A348, A356, A368, A378, A386, A394, A404, A416, A428, A440, A459, A478
N020	Foreign petroleum coke		A024
N021	Foreign petroleum coke		A025
N022	Petroleum coke in region 1	A024	A304, A320, A336, A443, A462, A481
N023	Petroleum coke in region 2	A025	A517, A518, A519, A520, A521, A522
N024	Foreign crude oil		A031, A032, A033, A034
N025	Crude oil in the well in region 3		A026
N026	Extracted crude oil in region 3	A026	A027, A028, A029, A030
N027	Crude oil at İzmit Refinery in region 1	A027, A031	A035, A036, A037, A038, A039, A040
N028	Crude oil at İzmir Refinery in region 1	A028, A032	A041, A042, A043, A044, A045, A046
N029	Crude oil at Kırıkkale Refinery in region 1	A029, A033	A047, A048, A049, A050, A051, A052
N030	Crude oil at Batman Refinery in region 1	A030, A034	A053, A054, A055, A056, A057, A058
N031	Gasoline in region 1	A035, A041, A059	A191, A207, A223
N032	Diesel oil in region 1	A036, A042, A062	A077, A078, A079, A194, A210, A226, A308, A324, A340, A447, A466, A485, A493, A497, A501
N033	Fuel oil in region 1	A037, A043, A065	A086, A087, A088, A147, A163, A179, A197, A213, A229, A241, A247, A253, A262, A275, A288, A301, A317, A333, A351, A359, A371, A379, A387, A395, A407, A419, A431, A450, A469, A488
N034	LPG in region 1	A038, A044, A068	A150, A166, A182, A200, A216, A232, A305, A321, A337, A444, A463, A482
N035	Jet fuel in region 1	A039, A045, A071	A203, A219, A235
N036	Other oil in region 1	A040, A046, A074	A265, A278, A291, A505, A508, A511
N037	Gasoline in region 2	A047, A060	A192, A208, A224
N038	Diesel oil in region 2	A048, A063	A080, A081, A082, A195, A211, A227, A309, A325, A341, A448, A467, A486, A494, A498, A502

Table B.1 (continued)

Node	Description	Entering Arcs	Leaving Arcs
N039	Fuel oil in region 2	A049, A066	A089, A090, A091, A148, A164, A180, A198, A214, A230, A242, A248, A254, A263, A276, A289, A302, A318, A334, A360, A372, A380, A388, A396, A408, A420, A432, A451, A470, A489, A523
N040	LPG in region 2	A050, A069	A151, A167, A183, A201, A217, A233, A306, A322, A338, A445, A464, A483
N041	Jet fuel in region 2	A051, A072	A204, A220, A236
N042	Other oil in region 2	A052, A075	A266, A279, A292, A506, A509, A512
N043	Gasoline in region 3	A053, A061	A193, A209, A225
N044	Diesel oil in region 3	A054, A064	A083, A084, A085, A196, A212, A228, A310, A326, A342, A449, A468, A487, A495, A499, A503
N045	Fuel oil in region 3	A055, A067	A092, A093, A094, A149, A165, A181, A199, A215, A231, A243, A249, A255, A264, A277, A290, A303, A319, A335, A361, A373, A381, A389, A397, A409, A421, A433, A452, A471, A490, A524
N046	LPG in region 3	A056, A070	A152, A168, A184, A202, A218, A234, A307, A323, A339, A446, A465, A484
N047	Jet fuel in region 3	A057, A073	A205, A221, A237
N048	Other oil in region 3	A058, A076	A267, A280, A293, A507, A510, A513
N049	Foreign refined oil products		A059, A060, A061, A062, A063, A064, A065, A066, A067, A068, A069, A070, A071, A072, A073, A074, A075, A076
N050	Natural gas in the well in region 1		A095
N051	Foreign natural gas		A096
N052	Foreign LNG		A097
N053	Gasified LNG in region 1	A097	A098
N054	Natural gas in the country	A095, A096, A098	A099, A100, A101, A153, A169, A185, A268, A281, A294, A362, A374, A382, A390, A398, A410, A422, A434, A453, A472, A491, A525
N055	Solar potential in the country		A155, A171, A187

Table B.1 (continued)

Node	Description	Entering Arcs	Leaving Arcs
N056	Geothermal potential in the country		A154, A170, A186
N057	Wood and biomass potential in the country		A514, A515, A516
N058	Wind potential in region 1		A107
N059	Geothermal potential in region 1		A108
N060	Hydroelectric (large) potential in region 1		A109
N061	Hydroelectric (small) potential in region 1		A110
N062	Foreign electricity		A111
N063	Wind potential in region 2		A117
N064	Geothermal potential in region 2		A118
N065	Hydroelectric (large) potential in region 2		A119
N066	Hydroelectric (small) potential in region 2		A120
N067	Wind potential in region 3		A126
N068	Geothermal potential in region 3		A127
N069	Hydroelectric (large) potential in region 3		A128
N070	Hydroelectric (small) potential in region 3		A129
N071	Foreign electricity		A130
N072	Hard coal at power plant in region 1	A009, A012	A102
N073	Lignite at power plant in region 1	A021	A103
N074	Diesel oil at power plant in region 1	A077, A080, A083	A104
N075	Fuel oil at power plant in region 1	A086, A089, A092	A105
N076	Natural gas at power plant in region 1	A099	A106
N077	Hard coal at power plant in region 2	A010, A013	A112
N078	Lignite at power plant in region 2	A022	A113
N079	Diesel oil at power plant in region 2	A078, A081, A084	A114
N080	Fuel oil at power plant in region 2	A087, A090, A093	A115
N081	Natural gas at power plant in region 2	A100	A116
N082	Hard coal at power plant in region 3	A011, A014	A121
N083	Lignite at power plant in region 3	A023	A122
N084	Diesel oil at power plant in region 3	A079, A082, A085	A123
N085	Fuel oil at power plant in region 3	A088, A091, A094	A124
N086	Natural gas at power plant in region 3	A101	A125
N087	Electricity generated in region 1	A102, A103, A104, A105, A106, A107, A108, A109, A110, A111	A131, A133

Table B.1 (continued)

Node	Description	Entering Arcs	Leaving Arcs
N088	Electricity generated in region 2 + transmission from other regions	A112, A113, A114, A115, A116, A117, A118, A119, A120, A133, A136, A650	A134, A135, A137
N089	Electricity generated in region 3	A121, A122, A123, A124, A125, A126, A127, A128, A129, A130	A136, A138
N090	Electricity generated in region 1 + transmission from other regions	A131, A135	A132
N091	Electricity generated in region 3 + transmission from other regions	A137, A138	A139
N092	Electricity transmitted in region 1	A132	A188, A206, A244, A269, A311, A383, A411, A454, A496, A526
N093	Electricity transmitted in region 2	A134	A189, A222, A250, A282, A327, A363, A391, A423, A473, A500
N094	Electricity transmitted in region 3	A139	A190, A238, A256, A295, A343, A375, A399, A435, A492, A504
N095	Energy consumed in region 1 by residential sector	A153, A154, A155, A188, A514, A527, A528, A529, A530, A531	
N096	Energy consumed in region 2 by residential sector	A169, A170, A171, A189, A515, A532, A533, A534, A535, A536	
N097	Energy consumed in region 3 by residential sector	A185, A186, A187, A190, A516, A537, A538, A539, A540, A541	
N098	Energy consumed in region 1 by transportation sector	A206, A542, A543, A544, A545, A546	
N099	Energy consumed in region 2 by transportation sector	A222, A547, A548, A549, A550, A551	
N100	Energy consumed in region 3 by transportation sector	A238, A552, A553, A554, A555, A556	
N101	Energy consumed in region 1 by iron-steel industry sector	A244, A557, A558	

Table B.1 (continued)

Node	Description	Entering Arcs	Leaving Arcs
N102	Energy consumed in region 2 by iron-steel industry sector	A250, A559, A560	
N103	Energy consumed in region 3 by iron-steel industry sector	A256, A561, A562	
N104	Energy consumed in region 1 by petrochemicals industry sector	A268, A269, A563, A564, A565, A566	
N105	Energy consumed in region 2 by petrochemicals industry sector	A281, A282, A567, A568, A569, A570	
N106	Energy consumed in region 3 by petrochemicals industry sector	A294, A295, A571, A572, A573, A574	
N107	Energy consumed in region 1 by cement industry sector	A311, A575, A576, A577, A578, A579, A580	
N108	Energy consumed in region 2 by cement industry sector	A327, A581, A582, A583, A584, A585, A586	
N109	Energy consumed in region 3 by cement industry sector	A343, A587, A588, A589, A590, A591, A592	
N110	Energy consumed in region 1 by sugar industry sector	A525, A526, A593, A594, A595, A596	
N111	Energy consumed in region 2 by sugar industry sector	A362, A363, A597, A598, A599, A600	
N112	Energy consumed in region 3 by sugar industry sector	A374, A375, A601, A602, A603, A604	
N113	Energy consumed in region 1 by fertilizer industry sector	A382, A383, A605, A606	
N114	Energy consumed in region 2 by fertilizer industry sector	A390, A391, A607, A608	
N115	Energy consumed in region 3 by fertilizer industry sector	A398, A399, A609, A610	
N116	Energy consumed in region 1 by non-iron metals industry sector	A410, A411, A611, A612, A613, A614	
N117	Energy consumed in region 2 by non-iron metals industry sector	A422, A423, A615, A616, A617, A618	
N118	Energy consumed in region 3 by non-iron metals industry sector	A434, A435, A619, A620, A621, A622	

Table B.1 (continued)

Node	Description	Entering Arcs	Leaving Arcs
N119	Energy consumed in region 1 by other industries sector	A453, A454, A623, A624, A625, A626, A627, A628, A629	
N120	Energy consumed in region 2 by other industries sector	A472, A473, A630, A631, A632, A633, A634, A635, A636	
N121	Energy consumed in region 3 by other industries sector	A491, A492, A637, A638, A639, A640, A641, A642, A643	
N122	Energy consumed in region 1 by agriculture sector	A496, A644	
N123	Energy consumed in region 2 by agriculture sector	A500, A645	
N124	Energy consumed in region 3 by agriculture sector	A504, A646	
N125	Energy consumed in region 1 for non-energy uses	A647	
N126	Energy consumed in region 2 for non-energy uses	A648	
N127	Energy consumed in region 3 for non-energy uses	A649	
N128	Hard coal to be consumed in region 1 by the residential sector	A140, A141	A527
N129	Coke to be consumed in region 1 by the residential sector	A142, A143	A528
N130	Lignite to be consumed in region 1 by the residential sector	A144, A145, A146	A529
N131	Fuel oil to be consumed in region 1 by the residential sector	A147, A148, A149	A530
N132	LPG to be consumed in region 1 by the residential sector	A150, A151, A152	A531
N133	Hard coal to be consumed in region 2 by the residential sector	A156, A157	A532
N134	Coke to be consumed in region 2 by the residential sector	A158, A159	A533
N135	Lignite to be consumed in region 2 by the residential sector	A160, A161, A162	A534
N136	Fuel oil to be consumed in region 2 by the residential sector	A163, A164, A165	A535
N137	LPG to be consumed in region 2 by the residential sector	A166, A167, A168	A536
N138	Hard coal to be consumed in region 3 by the residential sector	A172, A173	A537

Table B.1 (continued)

Node	Description	Entering Arcs	Leaving Arcs
N139	Coke to be consumed in region 3 by the residential sector	A174, A175	A538
N140	Lignite to be consumed in region 3 by the residential sector	A176, A177, A178	A539
N141	Fuel oil to be consumed in region 3 by the residential sector	A179, A180, A181	A540
N142	LPG to be consumed in region 3 by the residential sector	A182, A183, A184	A541
N143	Gasoline to be consumed in region 1 by the transportation sector	A191, A192, A193	A542
N144	Diesel oil to be consumed in region 1 by the transportation sector	A194, A195, A196	A543
N145	Fuel oil to be consumed in region 1 by the transportation sector	A197, A198, A199	A544
N146	LPG to be consumed in region 1 by the transportation sector	A200, A201, A202	A545
N147	Jet fuel to be consumed in region 1 by the transportation sector	A203, A204, A205	A546
N148	Gasoline to be consumed in region 2 by the transportation sector	A207, A208, A209	A547
N149	Diesel oil to be consumed in region 2 by the transportation sector	A210, A211, A212	A548
N150	Fuel oil to be consumed in region 2 by the transportation sector	A213, A214, A215	A549
N151	LPG to be consumed in region 2 by the transportation sector	A216, A217, A218	A550
N152	Jet fuel to be consumed in region 2 by the transportation sector	A219, A220, A221	A551
N153	Gasoline to be consumed in region 3 by the transportation sector	A223, A224, A225	A552
N154	Diesel oil to be consumed in region 3 by the transportation sector	A226, A227, A228	A553
N155	Fuel oil to be consumed in region 3 by the transportation sector	A229, A230, A231	A554
N156	LPG to be consumed in region 3 by the transportation sector	A232, A233, A234	A555
N157	Jet fuel to be consumed in region 3 by the transportation sector	A235, A236, A237	A556
N158	Coke to be consumed in region 1 by the iron-steel industry sector	A239, A240	A557
N159	Fuel oil to be consumed in region 1 by the iron-steel industry sector	A241, A242, A243	A558
N156	LPG to be consumed in region 3 by the transportation sector	A232, A233, A234	A555
N157	Jet fuel to be consumed in region 3 by the transportation sector	A235, A236, A237	A556
N158	Coke to be consumed in region 1 by the iron-steel industry sector	A239, A240	A557
N159	Fuel oil to be consumed in region 1 by the iron-steel industry sector	A241, A242, A243	A558

Table B.1 (continued)

Node	Description	Entering Arcs	Leaving Arcs
N160	Coke to be consumed in region 2 by the iron-steel industry sector	A245, A246	A559
N161	Fuel oil to be consumed in region 2 by the iron-steel industry sector	A247, A248, A249	A560
N162	Coke to be consumed in region 3 by the iron-steel industry sector	A251, A252	A561
N163	Fuel oil to be consumed in region 3 by the iron-steel industry sector	A253, A254, A255	A562
N164	Hard coal to be consumed in region 1 by the petrochemicals industry sector	A257, A258	A563
N165	Lignite to be consumed in region 1 by the petrochemicals industry sector	A259, A260, A261	A564
N166	Fuel oil to be consumed in region 1 by the petrochemicals industry sector	A262, A263, A264	A565
N167	Other oil to be consumed in region 1 by the petrochemicals industry sector	A265, A266, A267	A566
N168	Hard coal to be consumed in region 2 by the petrochemicals industry sector	A270, A271	A567
N169	Lignite to be consumed in region 2 by the petrochemicals industry sector	A272, A273, A274	A568
N170	Fuel oil to be consumed in region 2 by the petrochemicals industry sector	A275, A276, A277	A569
N171	Other oil to be consumed in region 2 by the petrochemicals industry sector	A278, A279, A280	A570
N172	Hard coal to be consumed in region 3 by the petrochemicals industry sector	A283, A284	A571
N173	Lignite to be consumed in region 3 by the petrochemicals industry sector	A285, A286, A287	A572
N174	Fuel oil to be consumed in region 3 by the petrochemicals industry sector	A288, A289, A290	A573
N175	Other oil to be consumed in region 3 by the petrochemicals industry sector	A291, A292, A293	A574
N176	Hard coal to be consumed in region 1 by the cement industry sector	A296, A297	A575
N177	Lignite to be consumed in region 1 by the cement industry sector	A298, A299, A300	A576
N178	Fuel oil to be consumed in region 1 by the cement industry sector	A301, A302, A303	A577
N179	LPG to be consumed in region 1 by the cement industry sector	A305, A306, A307	A578
N180	Petroleum coke to be consumed in region 1 by the cement industry sector	A304, A520	A580
N181	Diesel oil to be consumed in region 1 by the cement industry sector	A308, A309, A310	A579
N182	Hard coal to be consumed in region 2 by the cement industry sector	A312, A313	A581
N183	Lignite to be consumed in region 2 by the cement industry sector	A314, A315, A316	A582
N184	Fuel oil to be consumed in region 2 by the cement industry sector	A317, A318, A319	A583

Table B.1 (continued)

Node	Description	Entering Arcs	Leaving Arcs
N185	Petroleum coke to be consumed in region 2 by the cement industry sector	A320, A521	A586
N186	LPG to be consumed in region 2 by the cement industry sector	A321, A322, A323	A584
N187	Diesel oil to be consumed in region 2 by the cement industry sector	A324, A325, A326	A585
N188	Hard coal to be consumed in region 3 by the cement industry sector	A328, A329	A587
N189	Lignite to be consumed in region 3 by the cement industry sector	A330, A331, A332	A588
N190	Fuel oil to be consumed in region 3 by the cement industry sector	A333, A334, A335	A589
N191	Petroleum coke to be consumed in region 3 by the cement industry sector	A336, A522	A592
N192	LPG to be consumed in region 3 by the cement industry sector	A337, A338, A339	A590
N193	Diesel oil to be consumed in region 3 by the cement industry sector	A340, A341, A342	A591
N194	Hard coal to be consumed in region 1 by the sugar industry sector	A344, A345	A593
N195	Lignite to be consumed in region 1 by the sugar industry sector	A346, A347, A348	A594
N196	Coke to be consumed in region 1 by the sugar industry sector	A349, A350	A595
N197	Fuel oil to be consumed in region 1 by the sugar industry sector	A351, A523, A524	A596
N198	Hard coal to be consumed in region 2 by the sugar industry sector	A352, A353	A597
N199	Lignite to be consumed in region 2 by the sugar industry sector	A354, A355, A356	A598
N200	Coke to be consumed in region 2 by the sugar industry sector	A357, A358	A599
N201	Fuel oil to be consumed in region 2 by the sugar industry sector	A359, A360, A361	A600
N202	Hard coal to be consumed in region 3 by the sugar industry sector	A364, A365	A601
N203	Lignite to be consumed in region 3 by the sugar industry sector	A366, A367, A368	A602
N204	Coke to be consumed in region 3 by the sugar industry sector	A369, A370	A603
N205	Fuel oil to be consumed in region 3 by the sugar industry sector	A371, A372, A373	A604
N206	Lignite to be consumed in region 1 by the fertilizer industry sector	A376, A377, A378	A605
N207	Fuel oil to be consumed in region 1 by the fertilizer industry sector	A379, A380, A381	A606
N208	Lignite to be consumed in region 2 by the fertilizer industry sector	A384, A385, A386	A607
N209	Fuel oil to be consumed in region 2 by the fertilizer industry sector	A387, A388, A389	A608

Table B.1 (continued)

Node	Description	Entering Arcs	Leaving Arcs
N210	Lignite to be consumed in region 3 by the fertilizer industry sector	A392, A393, A394	A609
N211	Fuel oil to be consumed in region 3 by the fertilizer industry sector	A395, A396, A397	A610
N212	Hard coal to be consumed in region 1 by the non-iron metals industry sector	A400, A401	A611
N213	Lignite to be consumed in region 1 by the non-iron metals industry sector	A402, A403, A404	A612
N214	Coke to be consumed in region 1 by the non-iron metals industry sector	A405, A406	A613
N215	Fuel oil to be consumed in region 1 by the non-iron metals industry sector	A407, A408, A409	A614
N216	Hard coal to be consumed in region 2 by the non-iron metals industry sector	A412, A413	A615
N217	Lignite to be consumed in region 2 by the non-iron metals industry sector	A414, A415, A416	A616
N218	Coke to be consumed in region 2 by the non-iron metals industry sector	A417, A418	A617
N219	Fuel oil to be consumed in region 2 by the non-iron metals industry sector	A419, A420, A421	A618
N220	Hard coal to be consumed in region 3 by the non-iron metals industry sector	A424, A425	A619
N221	Lignite to be consumed in region 3 by the non-iron metals industry sector	A426, A427, A428	A620
N222	Coke to be consumed in region 3 by the non-iron metals industry sector	A429, A430	A621
N223	Fuel oil to be consumed in region 3 by the non-iron metals industry sector	A431, A432, A433	A622
N224	Hard coal to be consumed in region 1 by the other industries sector	A436, A437	A623
N225	Lignite to be consumed in region 1 by the other industries sector	A438, A439, A440	A624
N226	Coke to be consumed in region 1 by the other industries sector	A441, A442	A625
N227	Petroleum coke to be consumed in region 1 by the other industries sector	A443, A517	A626
N228	LPG to be consumed in region 1 by the other industries sector	A444, A445, A446	A627
N229	Diesel oil to be consumed in region 1 by the other industries sector	A447, A448, A449	A628
N230	Fuel oil to be consumed in region 1 by the other industries sector	A450, A451, A452	A629
N231	Hard coal to be consumed in region 2 by the other industries sector	A455, A456	A630
N232	Lignite to be consumed in region 2 by the other industries sector	A457, A458, A459	A631
N233	Coke to be consumed in region 2 by the other industries sector	A460, A461	A632
N234	Petroleum coke to be consumed in region 2 by the other industries sector	A462, A518	A633

Table B.1 (continued)

Node	Description	Entering Arcs	Leaving Arcs
N235	LPG to be consumed in region 2 by the other industries sector	A463, A464, A465	A634
N236	Diesel oil to be consumed in region 2 by the other industries sector	A466, A467, A468	A635
N237	Fuel oil to be consumed in region 2 by the other industries sector	A469, A470, A471	A636
N238	Hard coal to be consumed in region 3 by the other industries sector	A474, A475	A637
N239	Lignite to be consumed in region 3 by the other industries sector	A476, A477, A478	A638
N240	Coke to be consumed in region 3 by the other industries sector	A479, A480	A639
N241	Petroleum coke to be consumed in region 3 by the other industries sector	A481, A519	A640
N242	LPG to be consumed in region 3 by the other industries sector	A482, A483, A484	A641
N243	Diesel oil to be consumed in region 3 by the other industries sector	A485, A486, A487	A642
N244	Fuel oil to be consumed in region 3 by the other industries sector	A488, A489, A490	A643
N245	Diesel oil to be consumed in region 1 by the agriculture sector	A493, A494, A495	A644
N246	Diesel oil to be consumed in region 2 by the agriculture sector	A497, A498, A499	A645
N247	Diesel oil to be consumed in region 3 by the agriculture sector	A501, A502, A503	A646
N248	Other oil to be consumed in region 1 by the non-energy uses	A505, A506, A507	A647
N249	Other oil to be consumed in region 2 by the non-energy uses	A508, A509, A510	A648
N250	Other oil to be consumed in region 3 by the non-energy uses	A511, A512, A513	A649
N251	Foreign nuclear fuel		A650

Table B.2 Description of Network Arcs

Arc	Description	From	To
A001	Coke importing to region 1	N001	N006
A002	Hard coal importing to region 1	N002	N005
A003	Hard coal extraction in region 1	N003	N004
A004	Hard coal washing in region 1	N004	N005
A005	Hard coal coking in region 1	N005	N006
A006	Coke importing to region 2	N007	N010
A007	Hard coal importing to region 2	N008	N009
A008	Hard coal coking in region 2	N009	N010
A009	Hard coal transportation from region 1 to power plants in region 1	N005	N072
A010	Hard coal transportation from region 1 to power plants in region 2	N005	N077
A011	Hard coal transportation from region 1 to power plants in region 3	N005	N082
A012	Hard coal transportation from region 2 to power plants in region 1	N009	N072
A013	Hard coal transportation from region 2 to power plants in region 2	N009	N077
A014	Hard coal transportation from region 2 to power plants in region 3	N009	N082
A015	Lignite extraction in region 1	N011	N014
A016	Lignite extraction in region 2	N012	N015
A017	Lignite extraction in region 3	N013	N016
A018	Lignite washing in region 1	N014	N017
A019	Lignite washing in region 2	N015	N018
A020	Lignite washing in region 3	N016	N019
A021	Lignite transportation from region 1 to power plants in region 1	N014	N073
A022	Lignite transportation from region 2 to power plants in region 2	N015	N078
A023	Lignite transportation from region 3 to power plants in region 3	N016	N083
A024	Petroleum coke importing to region 1	N020	N022
A025	Petroleum coke importing to region 2	N021	N023
A026	Crude oil extraction in region 1	N025	N026
A027	Domestic crude oil transportation to refinery in Izmit	N026	N027
A028	Domestic crude oil transportation to refinery in Izmir	N026	N028
A029	Domestic crude oil transportation to refinery in Kirikkale	N026	N029
A030	Domestic crude oil transportation to refinery in Batman	N026	N030
A031	Crude oil importing to refinery in Izmit	N024	N027
A032	Crude oil importing to refinery in Izmir	N024	N028
A033	Crude oil importing to refinery in Kirikkale	N024	N029
A034	Crude oil importing to refinery in Batman	N024	N030
A035	Gasoline production in refinery in Izmit	N027	N031
A036	Diesel oil production in refinery in Izmit	N027	N032
A037	Fuel oil production in refinery in Izmit	N027	N033
A038	LPG production in refinery in Izmit	N027	N034
A039	Kerosene production in refinery in Izmit	N027	N035
A040	Other oil production in refinery in Izmit	N027	N036
A041	Gasoline production in refinery in Izmir	N028	N031
A042	Diesel oil production in refinery in Izmir	N028	N032
A043	Fuel oil production in refinery in Izmir	N028	N033
A044	LPG production in refinery in Izmir	N028	N034
A045	Kerosene production in refinery in Izmir	N028	N035
A046	Other oil production in refinery in Izmir	N028	N036
A047	Gasoline production in refinery in Kirikkale	N029	N037
A048	Diesel oil production in refinery in Kirikkale	N029	N038
A049	Fuel oil production in refinery in Kirikkale	N029	N039

Table B.2 (continued)

Arc	Description	From	To
A050	LPG production in refinery in Kirikkale	N029	N040
A051	Kerosene production in refinery in Kirikkale	N029	N041
A052	Other oil production in refinery in Kirikkale	N029	N042
A053	Gasoline production in refinery in Batman	N030	N043
A054	Diesel oil production in refinery in Batman	N030	N044
A055	Fuel oil production in refinery in Batman	N030	N045
A056	LPG production in refinery in Batman	N030	N046
A057	Kerosene production in refinery in Batman	N030	N047
A058	Other oil production in refinery in Batman	N030	N048
A059	Gasoline importing to region 1	N049	N031
A060	Gasoline importing to region 2	N049	N037
A061	Gasoline importing to region 3	N049	N043
A062	Diesel oil importing to region 1	N049	N032
A063	Diesel oil importing to region 2	N049	N038
A064	Diesel oil importing to region 3	N049	N044
A065	Fuel oil importing to region 1	N049	N033
A066	Fuel oil importing to region 2	N049	N039
A067	Fuel oil importing to region 3	N049	N045
A068	LPG importing to region 1	N049	N034
A069	LPG importing to region 2	N049	N040
A070	LPG importing to region 3	N049	N046
A071	Kerosene importing to region 1	N049	N035
A072	Kerosene importing to region 2	N049	N041
A073	Kerosene importing to region 3	N049	N047
A074	Other oil importing to region 1	N049	N036
A075	Other oil importing to region 2	N049	N042
A076	Other oil importing to region 3	N049	N048
A077	Diesel oil transportation from region 1 to power plants in region 1	N032	N074
A078	Diesel oil transportation from region 1 to power plants in region 2	N032	N079
A079	Diesel oil transportation from region 1 to power plants in region 3	N032	N084
A080	Diesel oil transportation from region 2 to power plants in region 1	N038	N074
A081	Diesel oil transportation from region 2 to power plants in region 2	N038	N079
A082	Diesel oil transportation from region 2 to power plants in region 3	N038	N084
A083	Diesel oil transportation from region 3 to power plants in region 1	N044	N074
A084	Diesel oil transportation from region 3 to power plants in region 2	N044	N079
A085	Diesel oil transportation from region 3 to power plants in region 3	N044	N084
A086	Fuel oil transportation from region 1 to power plants in region 1	N033	N075
A087	Fuel oil transportation from region 1 to power plants in region 2	N033	N080
A088	Fuel oil transportation from region 1 to power plants in region 3	N033	N085
A089	Fuel oil transportation from region 2 to power plants in region 1	N039	N075
A090	Fuel oil transportation from region 2 to power plants in region 2	N039	N080
A091	Fuel oil transportation from region 2 to power plants in region 3	N039	N085
A092	Fuel oil transportation from region 3 to power plants in region 1	N045	N075
A093	Fuel oil transportation from region 3 to power plants in region 2	N045	N080
A094	Fuel oil transportation from region 3 to power plants in region 3	N045	N085
A095	Natural gas importing from west	N050	N054
A096	Natural gas importing from east	N051	N054
A097	LNG importing	N052	N053
A098	LNG gasification	N053	N054

Table B.2 (continued)

Arc	Description	From	To
A099	Natural gas transportation to power plants in region 1	N054	N076
A100	Natural gas transportation to power plants in region 2	N054	N081
A101	Natural gas transportation to power plants in region 3	N054	N086
A102	Power generation by hard coal plants in region 1	N072	N087
A103	Power generation by lignite plants in region 1	N073	N087
A104	Power generation by diesel oil plants in region 1	N074	N087
A105	Power generation by fuel oil plants in region 1	N075	N087
A106	Power generation by natural gas plants in region 1	N076	N087
A107	Power generation by wind turbines in region 1	N058	N087
A108	Power generation by geothermal plants in region 1	N059	N087
A109	Power generation by hydroelectric plants with dam in region 1	N060	N087
A110	Power generation by hydroelectric plants without dam in region 1	N061	N087
A111	Electricity import to region 1	N062	N087
A112	Power generation by hard coal plants in region 2	N077	N088
A113	Power generation by lignite plants in region 2	N078	N088
A114	Power generation by diesel oil plants in region 2	N079	N088
A115	Power generation by fuel oil plants in region 2	N080	N088
A116	Power generation by natural gas plants in region 2	N081	N088
A117	Power generation by wind turbines in region 2	N063	N088
A118	Power generation by geothermal plants in region 2	N064	N088
A119	Power generation by hydroelectric plants with dam in region 2	N065	N088
A120	Power generation by hydroelectric plants without dam in region 2	N066	N088
A121	Power generation by hard coal plants in region 3	N082	N089
A122	Power generation by lignite plants in region 3	N083	N089
A123	Power generation by diesel oil plants in region 3	N084	N089
A124	Power generation by fuel oil plants in region 3	N085	N089
A125	Power generation by natural gas plants in region 3	N086	N089
A126	Power generation by wind turbines in region 3	N067	N089
A127	Power generation by geothermal plants in region 3	N068	N089
A128	Power generation by hydroelectric plants with dam in region 3	N069	N089
A129	Power generation by hydroelectric plants without dam in region 3	N070	N089
A130	Electricity import to region 3	N071	N089
A131	Dummy arc to prevent flow in both directions	N087	N090
A132	Electricity transmission in region 1	N090	N092
A133	Electricity transmission from region 1 to region 2	N087	N088
A134	Electricity transmission in region 2	N088	N093
A135	Electricity transmission from region 2 to region 1	N088	N090
A136	Electricity transmission from region 3 to region 2	N089	N088
A137	Electricity transmission from region 2 to region 3	N088	N091
A138	Dummy arc to prevent flow in both directions	N089	N091
A139	Electricity transmission in region 3	N091	N094
A140	Hard coal transportation from region 1 to region 1 to satisfy residential demand	N005	N128
A141	Hard coal transportation from region 2 to region 1 to satisfy residential demand	N009	N128
A142	Coke transportation from region 1 to region 1 to satisfy residential demand	N006	N129
A143	Coke transportation from region 2 to region 1 to satisfy residential demand	N010	N129

Table B.2 (continued)

Arc	Description	From	To
A144	Lignite transportation from region 1 to region 1 to satisfy residential demand	N017	N130
A145	Lignite transportation from region 2 to region 1 to satisfy residential demand	N018	N130
A146	Lignite transportation from region 3 to region 1 to satisfy residential demand	N019	N130
A147	Fuel oil transportation from region 1 to region 1 to satisfy residential demand	N033	N131
A148	Fuel oil transportation from region 2 to region 1 to satisfy residential demand	N039	N131
A149	Fuel oil transportation from region 3 to region 1 to satisfy residential demand	N045	N131
A150	LPG transportation from region 1 to region 1 to satisfy residential demand	N034	N132
A151	LPG transportation from region 2 to region 1 to satisfy residential demand	N040	N132
A152	LPG transportation from region 3 to region 1 to satisfy residential demand	N046	N132
A153	Natural gas consumption in region 1 to satisfy residential demand	N054	N095
A154	Geothermal energy consumption in region 1 to satisfy residential demand	N056	N095
A155	Solar energy consumption in region 1 to satisfy residential demand	N055	N095
A156	Hard coal transportation from region 1 to region 2 to satisfy residential demand	N005	N133
A157	Hard coal transportation from region 2 to region 2 to satisfy residential demand	N009	N133
A158	Coke transportation from region 1 to region 2 to satisfy residential demand	N006	N134
A159	Coke transportation from region 2 to region 2 to satisfy residential demand	N010	N134
A160	Lignite transportation from region 1 to region 2 to satisfy residential demand	N017	N135
A161	Lignite transportation from region 2 to region 2 to satisfy residential demand	N018	N135
A162	Lignite transportation from region 3 to region 2 to satisfy residential demand	N019	N135
A163	Fuel oil transportation from region 1 to region 2 to satisfy residential demand	N033	N136
A164	Fuel oil transportation from region 2 to region 2 to satisfy residential demand	N039	N136
A165	Fuel oil transportation from region 3 to region 2 to satisfy residential demand	N045	N136
A166	LPG transportation from region 1 to region 2 to satisfy residential demand	N034	N137
A167	LPG transportation from region 2 to region 2 to satisfy residential demand	N040	N137
A168	LPG transportation from region 3 to region 2 to satisfy residential demand	N046	N137
A169	Natural gas consumption in region 2 to satisfy residential demand	N054	N096

Table B.2 (continued)

Arc	Description	From	To
A170	Geothermal energy consumption in region 2 to satisfy residential demand	N056	N096
A171	Solar energy consumption in region 2 to satisfy residential demand	N055	N096
A172	Hard coal transportation from region 1 to region 3 to satisfy residential demand	N005	N138
A173	Hard coal transportation from region 2 to region 3 to satisfy residential demand	N009	N138
A174	Coke transportation from region 1 to region 3 to satisfy residential demand	N006	N139
A175	Coke transportation from region 2 to region 3 to satisfy residential demand	N010	N139
A176	Lignite transportation from region 1 to region 3 to satisfy residential demand	N017	N140
A177	Lignite transportation from region 2 to region 3 to satisfy residential demand	N018	N140
A178	Lignite transportation from region 3 to region 3 to satisfy residential demand	N019	N140
A179	Fuel oil transportation from region 1 to region 3 to satisfy residential demand	N033	N141
A180	Fuel oil transportation from region 2 to region 3 to satisfy residential demand	N039	N141
A181	Fuel oil transportation from region 3 to region 3 to satisfy residential demand	N045	N141
A182	LPG transportation from region 1 to region 3 to satisfy residential demand	N034	N142
A183	LPG transportation from region 2 to region 3 to satisfy residential demand	N040	N142
A184	LPG transportation from region 3 to region 3 to satisfy residential demand	N046	N142
A185	Natural gas consumption in region 3 to satisfy residential demand	N054	N097
A186	Geothermal energy consumption in region 3 to satisfy residential demand	N056	N097
A187	Solar energy consumption in region 3 to satisfy residential demand	N055	N097
A188	Electricity consumption in region 1 to satisfy residential demand	N092	N095
A189	Electricity consumption in region 2 to satisfy residential demand	N093	N096
A190	Electricity consumption in region 3 to satisfy residential demand	N094	N097
A191	Gasoline transportation from region 1 to region 1 to satisfy transportation demand	N031	N143
A192	Gasoline transportation from region 2 to region 1 to satisfy transportation demand	N037	N143
A193	Gasoline transportation from region 3 to region 1 to satisfy transportation demand	N043	N143
A194	Diesel oil transportation from region 1 to region 1 to satisfy transportation demand	N032	N144
A195	Diesel oil transportation from region 2 to region 1 to satisfy transportation demand	N038	N144
A196	Diesel oil transportation from region 3 to region 1 to satisfy transportation demand	N044	N144
A197	Fuel oil transportation from region 1 to region 1 to satisfy transportation demand	N033	N145

Table B.2 (continued)

Arc	Description	From	To
A198	Fuel oil transportation from region 2 to region 1 to satisfy transportation demand	N039	N145
A199	Fuel oil transportation from region 3 to region 1 to satisfy transportation demand	N045	N145
A200	LPG transportation from region 1 to region 1 to satisfy transportation demand	N034	N146
A201	LPG transportation from region 2 to region 1 to satisfy transportation demand	N040	N146
A202	LPG transportation from region 3 to region 1 to satisfy transportation demand	N046	N146
A203	Kerosene transportation from region 1 to region 1 to satisfy transportation demand	N035	N147
A204	Kerosene transportation from region 2 to region 1 to satisfy transportation demand	N041	N147
A205	Kerosene transportation from region 3 to region 1 to satisfy transportation demand	N047	N147
A206	Electricity consumption in region 1 to satisfy trasnportation demand	N092	N098
A207	Gasoline transportation from region 1 to region 2 to satisfy transportation demand	N031	N148
A208	Gasoline transportation from region 2 to region 2 to satisfy transportation demand	N037	N148
A209	Gasoline transportation from region 3 to region 2 to satisfy transportation demand	N043	N148
A210	Diesel oil transportation from region 1 to region 2 to satisfy transportation demand	N032	N149
A211	Diesel oil transportation from region 2 to region 2 to satisfy transportation demand	N038	N149
A212	Diesel oil transportation from region 3 to region 2 to satisfy transportation demand	N044	N149
A213	Fuel oil transportation from region 1 to region 2 to satisfy transportation demand	N033	N150
A214	Fuel oil transportation from region 2 to region 2 to satisfy transportation demand	N039	N150
A215	Fuel oil transportation from region 3 to region 2 to satisfy transportation demand	N045	N150
A216	LPG transportation from region 1 to region 2 to satisfy transportation demand	N034	N151
A217	LPG transportation from region 2 to region 2 to satisfy transportation demand	N040	N151
A218	LPG transportation from region 3 to region 2 to satisfy transportation demand	N046	N151
A219	Kerosene transportation from region 1 to region 2 to satisfy transportation demand	N035	N152
A220	Kerosene transportation from region 2 to region 2 to satisfy transportation demand	N041	N152
A221	Kerosene transportation from region 3 to region 2 to satisfy transportation demand	N047	N152
A222	Electricity consumption in region 2 to satisfy trasnportation demand	N093	N099
A223	Gasoline transportation from region 1 to region 3 to satisfy transportation demand	N031	N153

Table B.2 (continued)

Arc	Description	From	To
A224	Gasoline transportation from region 2 to region 3 to satisfy transportation demand	N037	N153
A225	Gasoline transportation from region 3 to region 3 to satisfy transportation demand	N043	N153
A226	Diesel oil transportation from region 1 to region 3 to satisfy transportation demand	N032	N154
A227	Diesel oil transportation from region 2 to region 3 to satisfy transportation demand	N038	N154
A228	Diesel oil transportation from region 3 to region 3 to satisfy transportation demand	N044	N154
A229	Fuel oil transportation from region 1 to region 3 to satisfy transportation demand	N033	N155
A230	Fuel oil transportation from region 2 to region 3 to satisfy transportation demand	N039	N155
A231	Fuel oil transportation from region 3 to region 3 to satisfy transportation demand	N045	N155
A232	LPG transportation from region 1 to region 3 to satisfy transportation demand	N034	N156
A233	LPG transportation from region 2 to region 3 to satisfy transportation demand	N040	N156
A234	LPG transportation from region 3 to region 3 to satisfy transportation demand	N046	N156
A235	Kerosene transportation from region 1 to region 3 to satisfy transportation demand	N035	N157
A236	Kerosene transportation from region 2 to region 3 to satisfy transportation demand	N041	N157
A237	Kerosene transportation from region 3 to region 3 to satisfy transportation demand	N047	N157
A238	Electricity consumption in region 3 to satisfy trasnportation demand	N094	N100
A239	Coke transportation from region 1 to region 1 to satisfy iron steel industry demand	N006	N158
A240	Coke transportation from region 2 to region 1 to satisfy iron steel industry demand	N010	N158
A241	Fuel oil transportation from region 1 to region 1 to satisfy iron steel industry demand	N033	N159
A242	Fuel oil transportation from region 2 to region 1 to satisfy iron steel industry demand	N039	N159
A243	Fuel oil transportation from region 3 to region 1 to satisfy iron steel industry demand	N045	N159
A244	Electricity consumption in region 1 to satisfy iron steel industry demand	N092	N101
A245	Coke transportation from region 1 to region 2 to satisfy iron steel industry demand	N006	N160
A246	Coke transportation from region 2 to region 2 to satisfy iron steel industry demand	N010	N160
A247	Fuel oil transportation from region 1 to region 2 to satisfy iron steel industry demand	N033	N161
A248	Fuel oil transportation from region 2 to region 2 to satisfy iron steel industry demand	N039	N161

Table B.2 (continued)

Arc	Description	From	To
A249	Fuel oil transportation from region 3 to region 2 to satisfy iron steel industry demand	N045	N161
A250	Electricity consumption in region 2 to satisfy iron steel industry demand	N093	N102
A251	Coke transportation from region 1 to region 3 to satisfy iron steel industry demand	N006	N162
A252	Coke transportation from region 2 to region 3 to satisfy iron steel industry demand	N010	N162
A253	Fuel oil transportation from region 1 to region 3 to satisfy iron steel industry demand	N033	N163
A254	Fuel oil transportation from region 2 to region 3 to satisfy iron steel industry demand	N039	N163
A255	Fuel oil transportation from region 3 to region 3 to satisfy iron steel industry demand	N045	N163
A256	Electricity consumption in region 3 to satisfy iron steel industry demand	N094	N103
A257	Hard coal transportation from region 1 to region 1 to satisfy petrochemicals industry demand	N005	N164
A258	Hard coal transportation from region 2 to region 1 to satisfy petrochemicals industry demand	N009	N164
A259	Lignite transportation from region 1 to region 1 to satisfy petrochemicals industry demand	N017	N165
A260	Lignite transportation from region 2 to region 1 to satisfy petrochemicals industry demand	N018	N165
A261	Lignite transportation from region 3 to region 1 to satisfy petrochemicals industry demand	N019	N165
A262	Fuel oil transportation from region 1 to region 1 to satisfy petrochemicals industry demand	N033	N166
A263	Fuel oil transportation from region 2 to region 1 to satisfy petrochemicals industry demand	N039	N166
A264	Fuel oil transportation from region 3 to region 1 to satisfy petrochemicals industry demand	N045	N166
A265	Other oil transportation from region 1 to region 1 to satisfy petrochemicals industry demand	N036	N167
A266	Other oil transportation from region 2 to region 1 to satisfy petrochemicals industry demand	N042	N167
A267	Other oil transportation from region 3 to region 1 to satisfy petrochemicals industry demand	N048	N167
A268	Natural gas consumption in region 1 to satisfy petrochemicals industry demand	N054	N104
A269	Electricity consumption in region 1 to satisfy petrochemicals industry demand	N092	N104
A270	Hard coal transportation from region 1 to region 2 to satisfy petrochemicals industry demand	N005	N168
A271	Hard coal transportation from region 2 to region 2 to satisfy petrochemicals industry demand	N009	N168
A272	Lignite transportation from region 1 to region 2 to satisfy petrochemicals industry demand	N017	N169
A273	Lignite transportation from region 2 to region 2 to satisfy petrochemicals industry demand	N018	N169

Table B.2 (continued)

Arc	Description	From	To
A274	Lignite transportation from region 3 to region 2 to satisfy petrochemicals industry demand	N019	N169
A275	Fuel oil transportation from region 1 to region 2 to satisfy petrochemicals industry demand	N033	N170
A276	Fuel oil transportation from region 2 to region 2 to satisfy petrochemicals industry demand	N039	N170
A277	Fuel oil transportation from region 3 to region 2 to satisfy petrochemicals industry demand	N045	N170
A278	Other oil transportation from region 1 to region 2 to satisfy petrochemicals industry demand	N036	N171
A279	Other oil transportation from region 2 to region 2 to satisfy petrochemicals industry demand	N042	N171
A280	Other oil transportation from region 3 to region 2 to satisfy petrochemicals industry demand	N048	N171
A281	Natural gas consumption in region 2 to satisfy petrochemicals industry demand	N054	N105
A282	Electricity consumption in region 2 to satisfy petrochemicals industry demand	N093	N105
A283	Hard coal transportation from region 1 to region 3 to satisfy petrochemicals industry demand	N005	N172
A284	Hard coal transportation from region 2 to region 3 to satisfy petrochemicals industry demand	N009	N172
A285	Lignite transportation from region 1 to region 3 to satisfy petrochemicals industry demand	N017	N173
A286	Lignite transportation from region 2 to region 3 to satisfy petrochemicals industry demand	N018	N173
A287	Lignite transportation from region 3 to region 3 to satisfy petrochemicals industry demand	N019	N173
A288	Fuel oil transportation from region 1 to region 3 to satisfy petrochemicals industry demand	N033	N174
A289	Fuel oil transportation from region 2 to region 3 to satisfy petrochemicals industry demand	N039	N174
A290	Fuel oil transportation from region 3 to region 3 to satisfy petrochemicals industry demand	N045	N174
A291	Other oil transportation from region 1 to region 3 to satisfy petrochemicals industry demand	N036	N175
A292	Other oil transportation from region 2 to region 3 to satisfy petrochemicals industry demand	N042	N175
A293	Other oil transportation from region 3 to region 3 to satisfy petrochemicals industry demand	N048	N175
A294	Natural gas consumption in region 3 to satisfy petrochemicals industry demand	N054	N106
A295	Electricity consumption in region 3 to satisfy petrochemicals industry demand	N094	N106
A296	Hard coal transportation from region 1 to region 1 to satisfy cement industry demand	N005	N176
A297	Hard coal transportation from region 2 to region 1 to satisfy cement industry demand	N009	N176
A298	Lignite transportation from region 1 to region 1 to satisfy cement industry demand	N017	N177

Table B.2 (continued)

Arc	Description	From	To
A299	Lignite transportation from region 2 to region 1 to satisfy cement industry demand	N018	N177
A300	Lignite transportation from region 3 to region 1 to satisfy cement industry demand	N019	N177
A301	Fuel oil transportation from region 1 to region 1 to satisfy cement industry demand	N033	N178
A302	Fuel oil transportation from region 2 to region 1 to satisfy cement industry demand	N039	N178
A303	Fuel oil transportation from region 3 to region 1 to satisfy cement industry demand	N045	N178
A304	Petroleum coke transportation from region 1 to region 1 to satisfy cement industry demand	N022	N180
A305	LPG transportation from region 1 to region 1 to satisfy cement industry demand	N034	N179
A306	LPG transportation from region 2 to region 1 to satisfy cement industry demand	N040	N179
A307	LPG transportation from region 3 to region 1 to satisfy cement industry demand	N046	N179
A308	Diesel oil transportation from region 1 to region 1 to satisfy cement industry demand	N032	N181
A309	Diesel oil transportation from region 2 to region 1 to satisfy cement industry demand	N038	N181
A310	Diesel oil transportation from region 3 to region 1 to satisfy cement industry demand	N044	N181
A311	Electricity consumption in region 1 to satisfy cement industry demand	N092	N107
A312	Hard coal transportation from region 1 to region 2 to satisfy cement industry demand	N005	N182
A313	Hard coal transportation from region 2 to region 2 to satisfy cement industry demand	N009	N182
A314	Lignite transportation from region 1 to region 2 to satisfy cement industry demand	N017	N183
A315	Lignite transportation from region 2 to region 2 to satisfy cement industry demand	N018	N183
A316	Lignite transportation from region 3 to region 2 to satisfy cement industry demand	N019	N183
A317	Fuel oil transportation from region 1 to region 2 to satisfy cement industry demand	N033	N184
A318	Fuel oil transportation from region 2 to region 2 to satisfy cement industry demand	N039	N184
A319	Fuel oil transportation from region 3 to region 2 to satisfy cement industry demand	N045	N184
A320	Petroleum coke transportation from region 1 to region 2 to satisfy cement industry demand	N022	N185
A321	LPG transportation from region 1 to region 2 to satisfy cement industry demand	N034	N186
A322	LPG transportation from region 2 to region 2 to satisfy cement industry demand	N040	N186
A323	LPG transportation from region 3 to region 2 to satisfy cement industry demand	N046	N186

Table B.2 (continued)

Arc	Description	From	To
A324	Diesel oil transportation from region 1 to region 2 to satisfy cement industry demand	N032	N187
A325	Diesel oil transportation from region 2 to region 2 to satisfy cement industry demand	N038	N187
A326	Diesel oil transportation from region 3 to region 2 to satisfy cement industry demand	N044	N187
A327	Electricity consumption in region 2 to satisfy cement industry demand	N093	N108
A328	Hard coal transportation from region 1 to region 3 to satisfy cement industry demand	N005	N188
A329	Hard coal transportation from region 2 to region 3 to satisfy cement industry demand	N009	N188
A330	Lignite transportation from region 1 to region 3 to satisfy cement industry demand	N017	N189
A331	Lignite transportation from region 2 to region 3 to satisfy cement industry demand	N018	N189
A332	Lignite transportation from region 3 to region 3 to satisfy cement industry demand	N019	N189
A333	Fuel oil transportation from region 1 to region 3 to satisfy cement industry demand	N033	N190
A334	Fuel oil transportation from region 2 to region 3 to satisfy cement industry demand	N039	N190
A335	Fuel oil transportation from region 3 to region 3 to satisfy cement industry demand	N045	N190
A336	Petroleum coke transportation from region 1 to region 3 to satisfy cement industry demand	N022	N191
A337	LPG transportation from region 1 to region 3 to satisfy cement industry demand	N034	N192
A338	LPG transportation from region 2 to region 3 to satisfy cement industry demand	N040	N192
A339	LPG transportation from region 3 to region 3 to satisfy cement industry demand	N046	N192
A340	Diesel oil transportation from region 1 to region 3 to satisfy cement industry demand	N032	N193
A341	Diesel oil transportation from region 2 to region 3 to satisfy cement industry demand	N038	N193
A342	Diesel oil transportation from region 3 to region 3 to satisfy cement industry demand	N044	N193
A343	Electricity consumption in region 3 to satisfy cement industry demand	N094	N109
A344	Hard coal transportation from region 1 to region 1 to satisfy sugar industry demand	N005	N194
A345	Hard coal transportation from region 2 to region 1 to satisfy sugar industry demand	N009	N194
A346	Lignite transportation from region 1 to region 1 to satisfy sugar industry demand	N017	N195
A347	Lignite transportation from region 2 to region 1 to satisfy sugar industry demand	N018	N195
A348	Lignite transportation from region 3 to region 1 to satisfy sugar industry demand	N019	N195
A349	Coke transportation from region 1 to region 1 to satisfy sugar industry demand	N006	N196

Table B.2 (continued)

Arc	Description	From	To
A350	Coke transportation from region 2 to region 1 to satisfy sugar industry demand	N010	N196
A351	Fuel oil transportation from region 1 to region 1 to satisfy sugar industry demand	N033	N197
A352	Hard coal transportation from region 1 to region 2 to satisfy sugar industry demand	N005	N198
A353	Hard coal transportation from region 2 to region 2 to satisfy sugar industry demand	N009	N198
A354	Lignite transportation from region 1 to region 2 to satisfy sugar industry demand	N017	N199
A355	Lignite transportation from region 2 to region 2 to satisfy sugar industry demand	N018	N199
A356	Lignite transportation from region 3 to region 2 to satisfy sugar industry demand	N019	N199
A357	Coke transportation from region 1 to region 2 to satisfy sugar industry demand	N006	N200
A358	Coke transportation from region 2 to region 2 to satisfy sugar industry demand	N010	N200
A359	Fuel oil transportation from region 1 to region 2 to satisfy sugar industry demand	N033	N201
A360	Fuel oil transportation from region 2 to region 2 to satisfy sugar industry demand	N039	N201
A361	Fuel oil transportation from region 3 to region 2 to satisfy sugar industry demand	N045	N201
A362	Natural gas consumption in region 2 to satisfy sugar industry demand	N054	N111
A363	Electricity consumption in region 2 to satisfy sugar industry demand	N093	N111
A364	Hard coal transportation from region 1 to region 3 to satisfy sugar industry demand	N005	N202
A365	Hard coal transportation from region 2 to region 3 to satisfy sugar industry demand	N009	N202
A366	Lignite transportation from region 1 to region 3 to satisfy sugar industry demand	N017	N203
A367	Lignite transportation from region 2 to region 3 to satisfy sugar industry demand	N018	N203
A368	Lignite transportation from region 3 to region 3 to satisfy sugar industry demand	N019	N203
A369	Coke transportation from region 1 to region 3 to satisfy sugar industry demand	N006	N204
A370	Coke transportation from region 2 to region 3 to satisfy sugar industry demand	N010	N204
A371	Fuel oil transportation from region 1 to region 3 to satisfy sugar industry demand	N033	N205
A372	Fuel oil transportation from region 2 to region 3 to satisfy sugar industry demand	N039	N205
A373	Fuel oil transportation from region 3 to region 3 to satisfy sugar industry demand	N045	N205
A374	Natural gas consumption in region 3 to satisfy sugar industry demand	N054	N112
A375	Electricity consumption in region 3 to satisfy sugar industry demand	N094	N112
A376	Lignite transportation from region 1 to region 1 to satisfy fertilizer industry demand	N017	N206

Table B.2 (continued)

Arc	Description	From	To
A377	Lignite transportation from region 2 to region 1 to satisfy fertilizer industry demand	N018	N206
A378	Lignite transportation from region 3 to region 1 to satisfy fertilizer industry demand	N019	N206
A379	Fuel oil transportation from region 1 to region 1 to satisfy fertilizer industry demand	N033	N207
A380	Fuel oil transportation from region 2 to region 1 to satisfy fertilizer industry demand	N039	N207
A381	Fuel oil transportation from region 3 to region 1 to satisfy fertilizer industry demand	N045	N207
A382	Natural gas consumption in region 1 to satisfy fertilizer industry demand	N054	N113
A383	Electricity consumption in region 1 to satisfy fertilizer industry demand	N092	N113
A384	Lignite transportation from region 1 to region 2 to satisfy fertilizer industry demand	N017	N208
A385	Lignite transportation from region 2 to region 2 to satisfy fertilizer industry demand	N018	N208
A386	Lignite transportation from region 3 to region 2 to satisfy fertilizer industry demand	N019	N208
A387	Fuel oil transportation from region 1 to region 2 to satisfy fertilizer industry demand	N033	N209
A388	Fuel oil transportation from region 2 to region 2 to satisfy fertilizer industry demand	N039	N209
A389	Fuel oil transportation from region 3 to region 2 to satisfy fertilizer industry demand	N045	N209
A390	Natural gas consumption in region 2 to satisfy fertilizer industry demand	N054	N114
A391	Electricity consumption in region 2 to satisfy fertilizer industry demand	N093	N114
A392	Lignite transportation from region 1 to region 3 to satisfy fertilizer industry demand	N017	N210
A393	Lignite transportation from region 2 to region 3 to satisfy fertilizer industry demand	N018	N210
A394	Lignite transportation from region 3 to region 3 to satisfy fertilizer industry demand	N019	N210
A395	Fuel oil transportation from region 1 to region 3 to satisfy fertilizer industry demand	N033	N211
A396	Fuel oil transportation from region 2 to region 3 to satisfy fertilizer industry demand	N039	N211
A397	Fuel oil transportation from region 3 to region 3 to satisfy fertilizer industry demand	N045	N211
A398	Natural gas consumption in region 3 to satisfy fertilizer industry demand	N054	N115
A399	Electricity consumption in region 3 to satisfy fertilizer industry demand	N094	N115
A400	Hard coal transportation from region 1 to region 1 to satisfy non iron metals industry demand	N005	N212
A401	Hard coal transportation from region 2 to region 1 to satisfy non iron metals industry demand	N009	N212

Table B.2 (continued)

Arc	Description	From	To
A402	Lignite transportation from region 1 to region 1 to satisfy non iron metals industry demand	N017	N213
A403	Lignite transportation from region 2 to region 1 to satisfy non iron metals industry demand	N018	N213
A404	Lignite transportation from region 3 to region 1 to satisfy non iron metals industry demand	N019	N213
A405	Coke transportation from region 1 to region 1 to satisfy non iron metals industry demand	N006	N214
A406	Coke transportation from region 2 to region 1 to satisfy non iron metals industry demand	N010	N214
A407	Fuel oil transportation from region 1 to region 1 to satisfy non iron metals industry demand	N033	N215
A408	Fuel oil transportation from region 2 to region 1 to satisfy non iron metals industry demand	N039	N215
A409	Fuel oil transportation from region 3 to region 1 to satisfy non iron metals industry demand	N045	N215
A410	Natural gas consumption in region 1 to satisfy non iron metals industry demand	N054	N116
A411	Electricity consumption in region 1 to satisfy non iron metals industry demand	N092	N116
A412	Hard coal transportation from region 1 to region 2 to satisfy non iron metals industry demand	N005	N216
A413	Hard coal transportation from region 2 to region 2 to satisfy non iron metals industry demand	N009	N216
A414	Lignite transportation from region 1 to region 2 to satisfy non iron metals industry demand	N017	N217
A415	Lignite transportation from region 2 to region 2 to satisfy non iron metals industry demand	N018	N217
A416	Lignite transportation from region 3 to region 2 to satisfy non iron metals industry demand	N019	N217
A417	Coke transportation from region 1 to region 2 to satisfy non iron metals industry demand	N006	N218
A418	Coke transportation from region 2 to region 2 to satisfy non iron metals industry demand	N010	N218
A419	Fuel oil transportation from region 1 to region 2 to satisfy non iron metals industry demand	N033	N219
A420	Fuel oil transportation from region 2 to region 2 to satisfy non iron metals industry demand	N039	N219
A421	Fuel oil transportation from region 3 to region 2 to satisfy non iron metals industry demand	N045	N219
A422	Natural gas consumption in region 2 to satisfy non iron metals industry demand	N054	N117
A423	Electricity consumption in region 2 to satisfy non iron metals industry demand	N093	N117
A424	Hard coal transportation from region 1 to region 3 to satisfy non iron metals industry demand	N005	N220
A425	Hard coal transportation from region 2 to region 3 to satisfy non iron metals industry demand	N009	N220
A426	Lignite transportation from region 1 to region 3 to satisfy non iron metals industry demand	N017	N221

Table B.2 (continued)

Arc	Description	From	To
A427	Lignite transportation from region 2 to region 3 to satisfy non iron metals industry demand	N018	N221
A428	Lignite transportation from region 3 to region 3 to satisfy non iron metals industry demand	N019	N221
A429	Coke transportation from region 1 to region 3 to satisfy non iron metals industry demand	N006	N222
A430	Coke transportation from region 2 to region 3 to satisfy non iron metals industry demand	N010	N222
A431	Fuel oil transportation from region 1 to region 3 to satisfy non iron metals industry demand	N033	N223
A432	Fuel oil transportation from region 2 to region 3 to satisfy non iron metals industry demand	N039	N223
A433	Fuel oil transportation from region 3 to region 3 to satisfy non iron metals industry demand	N045	N223
A434	Natural gas consumption in region 3 to satisfy non iron metals industry demand	N054	N118
A435	Electricity consumption in region 3 to satisfy non iron metals industry demand	N094	N118
A436	Hard coal transportation from region 1 to region 1 to satisfy other industry demand	N005	N224
A437	Hard coal transportation from region 2 to region 1 to satisfy other industry demand	N009	N224
A438	Lignite transportation from region 1 to region 1 to satisfy other industry demand	N017	N225
A439	Lignite transportation from region 2 to region 1 to satisfy other industry demand	N018	N225
A440	Lignite transportation from region 3 to region 1 to satisfy other industry demand	N019	N225
A441	Coke transportation from region 1 to region 1 to satisfy other industry demand	N006	N226
A442	Coke transportation from region 2 to region 1 to satisfy other industry demand	N010	N226
A443	Petroleum coke transportation from region 1 to region 1 to satisfy other industry demand	N022	N227
A444	LPG transportation from region 1 to region 1 to satisfy other industry demand	N034	N228
A445	LPG transportation from region 2 to region 1 to satisfy other industry demand	N040	N228
A446	LPG transportation from region 3 to region 1 to satisfy other industry demand	N046	N228
A447	Diesel oil transportation from region 1 to region 1 to satisfy other industry demand	N032	N229
A448	Diesel oil transportation from region 2 to region 1 to satisfy other industry demand	N038	N229
A449	Diesel oil transportation from region 3 to region 1 to satisfy other industry demand	N044	N229
A450	Fuel oil transportation from region 1 to region 1 to satisfy other industry demand	N033	N230
A451	Fuel oil transportation from region 2 to region 1 to satisfy other industry demand	N039	N230

Table B.2 (continued)

Arc	Description	From	To
A452	Fuel oil transportation from region 3 to region 1 to satisfy other industry demand	N045	N230
A453	Natural gas consumption in region 1 to satisfy other industry demand	N054	N119
A454	Electricity consumption in region 1 to satisfy other industry demand	N092	N119
A455	Hard coal transportation from region 1 to region 2 to satisfy other industry demand	N005	N231
A456	Hard coal transportation from region 2 to region 2 to satisfy other industry demand	N009	N231
A457	Lignite transportation from region 1 to region 2 to satisfy other industry demand	N017	N232
A458	Lignite transportation from region 2 to region 2 to satisfy other industry demand	N018	N232
A459	Lignite transportation from region 3 to region 2 to satisfy other industry demand	N019	N232
A460	Coke transportation from region 1 to region 2 to satisfy other industry demand	N006	N233
A461	Coke transportation from region 2 to region 2 to satisfy other industry demand	N010	N233
A462	Petroleum coke transportation from region 1 to region 2 to satisfy other industry demand	N022	N234
A463	LPG transportation from region 1 to region 2 to satisfy other industry demand	N034	N235
A464	LPG transportation from region 2 to region 2 to satisfy other industry demand	N040	N235
A465	LPG transportation from region 3 to region 2 to satisfy other industry demand	N046	N235
A466	Diesel oil transportation from region 1 to region 2 to satisfy other industry demand	N032	N236
A467	Diesel oil transportation from region 2 to region 2 to satisfy other industry demand	N038	N236
A468	Diesel oil transportation from region 3 to region 2 to satisfy other industry demand	N044	N236
A469	Fuel oil transportation from region 1 to region 2 to satisfy other industry demand	N033	N237
A470	Fuel oil transportation from region 2 to region 2 to satisfy other industry demand	N039	N237
A471	Fuel oil transportation from region 3 to region 2 to satisfy other industry demand	N045	N237
A472	Natural gas consumption in region 2 to satisfy other industry demand	N054	N120
A473	Electricity consumption in region 2 to satisfy other industry demand	N093	N120
A474	Hard coal transportation from region 1 to region 3 to satisfy other industry demand	N005	N238
A475	Hard coal transportation from region 2 to region 3 to satisfy other industry demand	N009	N238
A476	Lignite transportation from region 1 to region 3 to satisfy other industry demand	N017	N239
A477	Lignite transportation from region 2 to region 3 to satisfy other industry demand	N018	N239
A478	Lignite transportation from region 3 to region 3 to satisfy other industry demand	N019	N239

Table B.2 (continued)

Arc	Description	From	To
A479	Coke transportation from region 1 to region 3 to satisfy other industry demand	N006	N240
A480	Coke transportation from region 2 to region 3 to satisfy other industry demand	N010	N240
A481	Petroleum coke transportation from region 1 to region 3 to satisfy other industry demand	N022	N241
A482	LPG transportation from region 1 to region 3 to satisfy other industry demand	N034	N242
A483	LPG transportation from region 2 to region 3 to satisfy other industry demand	N040	N242
A484	LPG transportation from region 3 to region 3 to satisfy other industry demand	N046	N242
A485	Diesel oil transportation from region 1 to region 3 to satisfy other industry demand	N032	N243
A486	Diesel oil transportation from region 2 to region 3 to satisfy other industry demand	N038	N243
A487	Diesel oil transportation from region 3 to region 3 to satisfy other industry demand	N044	N243
A488	Fuel oil transportation from region 1 to region 3 to satisfy other industry demand	N033	N244
A489	Fuel oil transportation from region 2 to region 3 to satisfy other industry demand	N039	N244
A490	Fuel oil transportation from region 3 to region 3 to satisfy other industry demand	N045	N244
A491	Natural gas consumption in region 3 to satisfy other industry demand	N054	N121
A492	Electricity consumption in region 3 to satisfy other industry demand	N094	N121
A493	Diesel oil transportation from region 1 to region 1 to satisfy agricultural demand	N032	N245
A494	Diesel oil transportation from region 2 to region 1 to satisfy agricultural demand	N038	N245
A495	Diesel oil transportation from region 3 to region 1 to satisfy agricultural demand	N044	N245
A496	Electricity consumption in region 1 to satisfy agricultural demand	N092	N122
A497	Diesel oil transportation from region 1 to region 2 to satisfy agricultural demand	N032	N246
A498	Diesel oil transportation from region 2 to region 2 to satisfy agricultural demand	N038	N246
A499	Diesel oil transportation from region 3 to region 2 to satisfy agricultural demand	N044	N246
A500	Electricity consumption in region 2 to satisfy agricultural demand	N093	N123
A501	Diesel oil transportation from region 1 to region 3 to satisfy agricultural demand	N032	N247
A502	Diesel oil transportation from region 2 to region 3 to satisfy agricultural demand	N038	N247
A503	Diesel oil transportation from region 3 to region 3 to satisfy agricultural demand	N044	N247
A504	Electricity consumption in region 3 to satisfy agricultural demand	N094	N124
A505	Other oil transportation from region 1 to region 1 to satisfy non energy demand	N036	N248

Table B.2 (continued)

Arc	Description	From	To
A506	Other oil transportation from region 2 to region 1 to satisfy non energy demand	N042	N248
A507	Other oil transportation from region 3 to region 1 to satisfy non energy demand	N048	N248
A508	Other oil transportation from region 1 to region 2 to satisfy non energy demand	N036	N249
A509	Other oil transportation from region 2 to region 2 to satisfy non energy demand	N042	N249
A510	Other oil transportation from region 3 to region 2 to satisfy non energy demand	N048	N249
A511	Other oil transportation from region 1 to region 3 to satisfy non energy demand	N036	N250
A512	Other oil transportation from region 2 to region 3 to satisfy non energy demand	N042	N250
A513	Other oil transportation from region 3 to region 3 to satisfy non energy demand	N048	N250
A514	Wood and waste consumption in region 1 to satisfy residential demand	N057	N095
A515	Wood and waste consumption in region 2 to satisfy residential demand	N057	N096
A516	Wood and waste consumption in region 3 to satisfy residential demand	N057	N097
A517	Petroleum coke transportation from region 2 to region 1 to satisfy other industry demand	N023	N227
A518	Petroleum coke transportation from region 2 to region 2 to satisfy other industry demand	N023	N234
A519	Petroleum coke transportation from region 2 to region 3 to satisfy other industry demand	N023	N241
A520	Petroleum coke transportation from region 2 to region 1 to satisfy cement industry demand	N023	N180
A521	Petroleum coke transportation from region 2 to region 2 to satisfy cement industry demand	N023	N185
A522	Petroleum coke transportation from region 2 to region 2 to satisfy cement industry demand	N023	N191
A523	Fuel oil transportation from region 2 to region 1 to satisfy sugar industry demand	N039	N197
A524	Fuel oil transportation from region 3 to region 1 to satisfy sugar industry demand	N045	N197
A525	Natural gas consumption in region 1 to satisfy sugar industry demand	N054	N110
A526	Electricity consumption in region 1 to satisfy sugar industry demand	N092	N110
A527	Hard coal consumption in region 1 to satisfy residential demand	N128	N095
A528	Coke consumption in region 1 to satisfy residential demand	N129	N095
A529	Lignite consumption in region 1 to satisfy residential demand	N130	N095
A530	Fuel oil consumption in region 1 to satisfy residential demand	N131	N095
A531	LPG consumption in region 1 to satisfy residential demand	N132	N095
A532	Hard coal consumption in region 2 to satisfy residential demand	N133	N096
A533	Coke consumption in region 2 to satisfy residential demand	N134	N096
A534	Lignite consumption in region 2 to satisfy residential demand	N135	N096
A535	Fuel oil consumption in region 2 to satisfy residential demand	N136	N096
A536	LPG consumption in region 2 to satisfy residential demand	N137	N096

Table B.2 (continued)

Arc	Description	From	To
A537	Hard coal consumption in region 3 to satisfy residential demand	N138	N097
A538	Coke consumption in region 3 to satisfy residential demand	N139	N097
A539	Lignite consumption in region 3 to satisfy residential demand	N140	N097
A540	Fuel oil consumption in region 3 to satisfy residential demand	N141	N097
A541	LPG consumption in region 3 to satisfy residential demand	N142	N097
A542	Gasoline consumption in region 1 to satisfy transportation demand	N143	N098
A543	Diesel oil consumption in region 1 to satisfy transportation demand	N144	N098
A544	Fuel oil consumption in region 1 to satisfy transportation demand	N145	N098
A545	LPG consumption in region 1 to satisfy transportation demand	N146	N098
A546	Kerosene consumption in region 1 to satisfy transportation demand	N147	N098
A547	Gasoline consumption in region 2 to satisfy transportation demand	N148	N099
A548	Diesel oil consumption in region 2 to satisfy transportation demand	N149	N099
A549	Fuel oil consumption in region 2 to satisfy transportation demand	N150	N099
A550	LPG consumption in region 2 to satisfy transportation demand	N151	N099
A551	Kerosene consumption in region 2 to satisfy transportation demand	N152	N099
A552	Gasoline consumption in region 3 to satisfy transportation demand	N153	N100
A553	Diesel oil consumption in region 3 to satisfy transportation demand	N154	N100
A554	Fuel oil consumption in region 3 to satisfy transportation demand	N155	N100
A555	LPG consumption in region 3 to satisfy transportation demand	N156	N100
A556	Kerosene consumption in region 3 to satisfy transportation demand	N157	N100
A557	Coke consumption in region 1 to satisfy iron steel industry demand	N158	N101
A558	Fuel oil consumption in region 1 to satisfy iron steel industry demand	N159	N101
A559	Coke consumption in region 2 to satisfy iron steel industry demand	N160	N102
A560	Fuel oil consumption in region 2 to satisfy iron steel industry demand	N161	N102
A561	Coke consumption in region 3 to satisfy iron steel industry demand	N162	N103
A562	Fuel oil consumption in region 3 to satisfy iron steel industry demand	N163	N103
A563	Hard coal consumption in region 1 to satisfy petrochemicals industry demand	N164	N104
A564	Lignite consumption in region 1 to satisfy petrochemicals industry demand	N165	N104
A565	Fuel oil consumption in region 1 to satisfy petrochemicals industry demand	N166	N104
A566	Other oil consumption in region 1 to satisfy petrochemicals industry demand	N167	N104
A567	Hard coal consumption in region 2 to satisfy petrochemicals industry demand	N168	N105
A568	Lignite consumption in region 2 to satisfy petrochemicals industry demand	N169	N105
A569	Fuel oil consumption in region 2 to satisfy petrochemicals industry demand	N170	N105
A570	Other oil consumption in region 2 to satisfy petrochemicals industry demand	N171	N105
A571	Hard coal consumption in region 3 to satisfy petrochemicals industry demand	N172	N106
A572	Lignite consumption in region 3 to satisfy petrochemicals industry demand	N173	N106
A573	Fuel oil consumption in region 3 to satisfy petrochemicals industry demand	N174	N106
A574	Other oil consumption in region 3 to satisfy petrochemicals industry demand	N175	N106

Table B.2 (continued)

Arc	Description	From	To
A575	Hard coal consumption in region 1 to satisfy cement industry demand	N176	N107
A576	Lignite consumption in region 1 to satisfy cement industry demand	N177	N107
A577	Fuel oil consumption in region 1 to satisfy cement industry demand	N178	N107
A578	LPG consumption in region 1 to satisfy cement industry demand	N179	N107
A579	Diesel oil consumption in region 1 to satisfy cement industry demand	N181	N107
A580	Petroleum coke consumption in region 1 to satisfy cement industry demand	N180	N107
A581	Hard coal consumption in region 2 to satisfy cement industry demand	N182	N108
A582	Lignite consumption in region 2 to satisfy cement industry demand	N183	N108
A583	Fuel oil consumption in region 2 to satisfy cement industry demand	N184	N108
A584	LPG consumption in region 2 to satisfy cement industry demand	N186	N108
A585	Diesel oil consumption in region 2 to satisfy cement industry demand	N187	N108
A586	Petroleum coke consumption in region 2 to satisfy cement industry demand	N185	N108
A587	Hard coal consumption in region 3 to satisfy cement industry demand	N188	N109
A588	Lignite consumption in region 3 to satisfy cement industry demand	N189	N109
A589	Fuel oil consumption in region 3 to satisfy cement industry demand	N190	N109
A590	LPG consumption in region 3 to satisfy cement industry demand	N192	N109
A591	Diesel oil consumption in region 3 to satisfy cement industry demand	N193	N109
A592	Petroleum coke consumption in region 3 to satisfy cement industry demand	N191	N109
A593	Hard coal consumption in region 1 to satisfy sugar industry demand	N194	N110
A594	Lignite consumption in region 1 to satisfy sugar industry demand	N195	N110
A595	Coke consumption in region 1 to satisfy sugar industry demand	N196	N110
A596	Fuel oil consumption in region 1 to satisfy sugar industry demand	N197	N110
A597	Hard coal consumption in region 2 to satisfy sugar industry demand	N198	N111
A598	Lignite consumption in region 2 to satisfy sugar industry demand	N199	N111
A599	Coke consumption in region 2 to satisfy sugar industry demand	N200	N111
A600	Fuel oil consumption in region 2 to satisfy sugar industry demand	N201	N111
A601	Hard coal consumption in region 3 to satisfy sugar industry demand	N202	N112
A602	Lignite consumption in region 3 to satisfy sugar industry demand	N203	N112
A603	Coke consumption in region 3 to satisfy sugar industry demand	N204	N112
A604	Fuel oil consumption in region 3 to satisfy sugar industry demand	N205	N112
A605	Lignite consumption in region 1 to satisfy fertilizer industry demand	N206	N113
A606	Fuel oil consumption in region 1 to satisfy fertilizer industry demand	N207	N113
A607	Lignite consumption in region 2 to satisfy fertilizer industry demand	N208	N114
A608	Fuel oil consumption in region 2 to satisfy fertilizer industry demand	N209	N114
A609	Lignite consumption in region 3 to satisfy fertilizer industry demand	N210	N115
A610	Fuel oil consumption in region 3 to satisfy fertilizer industry demand	N211	N115
A611	Hard coal consumption in region 1 to satisfy non iron metals industry demand	N212	N116
A612	Lignite consumption in region 1 to satisfy non iron metals industry demand	N213	N116
A613	Coke consumption in region 1 to satisfy non iron metals industry demand	N214	N116
A614	Fuel oil consumption in region 1 to satisfy non iron metals industry demand	N215	N116
A615	Hard coal consumption in region 2 to satisfy non iron metals industry demand	N216	N117

Table B.2 (continued)

Arc	Description	From	To
A616	Lignite consumption in region 2 to satisfy non iron metals industry demand	N217	N117
A617	Coke consumption in region 2 to satisfy non iron metals industry demand	N218	N117
A618	Fuel oil consumption in region 2 to satisfy non iron metals industry demand	N219	N117
A619	Hard coal consumption in region 3 to satisfy non iron metals industry demand	N220	N118
A620	Lignite consumption in region 3 to satisfy non iron metals industry demand	N221	N118
A621	Coke consumption in region 3 to satisfy non iron metals industry demand	N222	N118
A622	Fuel oil consumption in region 3 to satisfy non iron metals industry demand	N223	N118
A623	Hard coal consumption in region 1 to satisfy other industry demand	N224	N119
A624	Lignite consumption in region 1 to satisfy other industry demand	N225	N119
A625	Coke consumption in region 1 to satisfy other industry demand	N226	N119
A626	Petroleum coke consumption in region 1 to satisfy other industry demand	N227	N119
A627	LPG consumption in region 1 to satisfy other industry demand	N228	N119
A628	Diesel oil consumption in region 1 to satisfy other industry demand	N229	N119
A629	Fuel oil consumption in region 1 to satisfy other industry demand	N230	N119
A630	Hard coal consumption in region 2 to satisfy other industry demand	N231	N120
A631	Lignite consumption in region 2 to satisfy other industry demand	N232	N120
A632	Coke consumption in region 2 to satisfy other industry demand	N233	N120
A633	Petroleum coke consumption in region 2 to satisfy other industry demand	N234	N120
A634	LPG consumption in region 2 to satisfy other industry demand	N235	N120
A635	Diesel oil consumption in region 2 to satisfy other industry demand	N236	N120
A636	Fuel oil consumption in region 2 to satisfy other industry demand	N237	N120
A637	Hard coal consumption in region 3 to satisfy other industry demand	N238	N121
A638	Lignite consumption in region 3 to satisfy other industry demand	N239	N121
A639	Coke consumption in region 3 to satisfy other industry demand	N240	N121
A640	Petroleum coke consumption in region 3 to satisfy other industry demand	N241	N121
A641	LPG consumption in region 3 to satisfy other industry demand	N242	N121
A642	Diesel oil consumption in region 3 to satisfy other industry demand	N243	N121
A643	Fuel oil consumption in region 3 to satisfy other industry demand	N244	N121
A644	Diesel oil consumption in region 1 to satisfy agricultural demand	N245	N122
A645	Diesel oil consumption in region 2 to satisfy agricultural demand	N246	N123
A646	Diesel oil consumption in region 3 to satisfy agricultural demand	N247	N124
A647	Other oil consumption in region 1 to satisfy non energy demand	N248	N125
A648	Other oil consumption in region 2 to satisfy non energy demand	N249	N126
A649	Other oil consumption in region 3 to satisfy non energy demand	N250	N127
A650	Nuclear electricty generation	N251	N088

Appendix C: Energy System Network

See figures C.1 to C.4 on pages 183-186 for the network..

Appendix D: Model Parameters

D.1 Demands

Table D.1 Demand Projections, General (source: [43] [47])

Year	Demand[1] Energy *(K toe)*	Demand[1] Electricity *(GWh)*	Demand[1] Peak Load *(MW)*
2003	64,991	110,743	21,729
2004	69,077	120,049	23,199
2005	70,827	128,456	25,000
2006	75,778	139,913	28,270
2007	80,697	152,788	30,560
2008	85,814	167,048	33,075
2009	91,172	182,695	35,815
2010	96,827	199,778	38,785
2011	102,676	218,545	41,965
2012	108,823	238,457	45,410
2013	114,923	259,555	49,030
2014	121,134	281,447	52,905
2015	127,656	304,194	57,050
2016	134,510	327,778	60,845
2017	141,711	352,218	65,245
2018	149,387	378,033	69,835
2019	157,431	404,055	74,585
2020	165,838	430,335	79,350

The demand data for general energy and electricity tabulated in Table D.1 is the aggregated form of the data for individual sectors. In the coming tables D.2 and D.3, this data is distributed between sectors. The further distributions between industry sectors and between regions are carried out by using statistics from TUIK.

[1] Actual projections include refinery consumption for general energy and electricity. In the above projections it is subtracted based on 2003 consumption of refineries.

Table D.2 Demand Projections by Sector, Energy

	Demand (K toe)				
Year	**Residential**	**Transportation**	**Industry**	**Agriculture**	**Non-Energy**
2003	19,634	12,395	27,777	3,086	2,098
2004	20,952	13,775	28,863	3,314	2,174
2005	21,649	14,298	29,203	3,476	2,201
2006	22,900	15,400	31,571	3,645	2,263
2007	24,250	16,550	33,761	3,810	2,326
2008	25,720	17,700	36,023	3,985	2,387
2009	27,300	18,790	38,461	4,170	2,451
2010	29,019	19,915	41,010	4,370	2,513
2011	30,800	21,100	43,629	4,571	2,576
2012	32,650	22,370	46,388	4,775	2,640
2013	34,500	23,700	49,029	4,988	2,706
2014	36,450	25,100	51,600	5,210	2,774
2015	38,507	26,541	54,322	5,443	2,844
2016	40,400	28,000	57,505	5,690	2,915
2017	42,150	29,480	61,150	5,943	2,988
2018	43,900	31,000	65,221	6,203	3,063
2019	45,700	32,500	69,616	6,475	3,140
2020	50,487	31,101	74,278	6,753	3,219

Table D.3 Demand Projections by Sector, Electricity

	Demand (K toe)				
Year	**Residential**	**Transportation**	**Industry**	**Agriculture**	**Non-Energy**
2003	4,482	77	4,651	315	-
2004	4,957	63	4,970	335	-
2005	5,186	91	5,425	345	-
2006	5,723	99	5,847	362	-
2007	6,235	108	6,417	380	-
2008	6,798	118	7,053	397	-
2009	7,418	130	7,750	415	-
2010	8,092	142	8,515	432	-
2011	8,849	156	9,340	449	-
2012	9,675	170	10,195	467	-
2013	10,535	186	11,114	486	-
2014	11,438	204	12,057	505	-
2015	12,335	223	13,077	525	-
2016	13,210	244	14,189	547	-
2017	14,087	267	15,369	569	-
2018	14,964	291	16,664	592	-
2019	15,884	318	17,930	616	-
2020	16,796	348	19,224	641	-

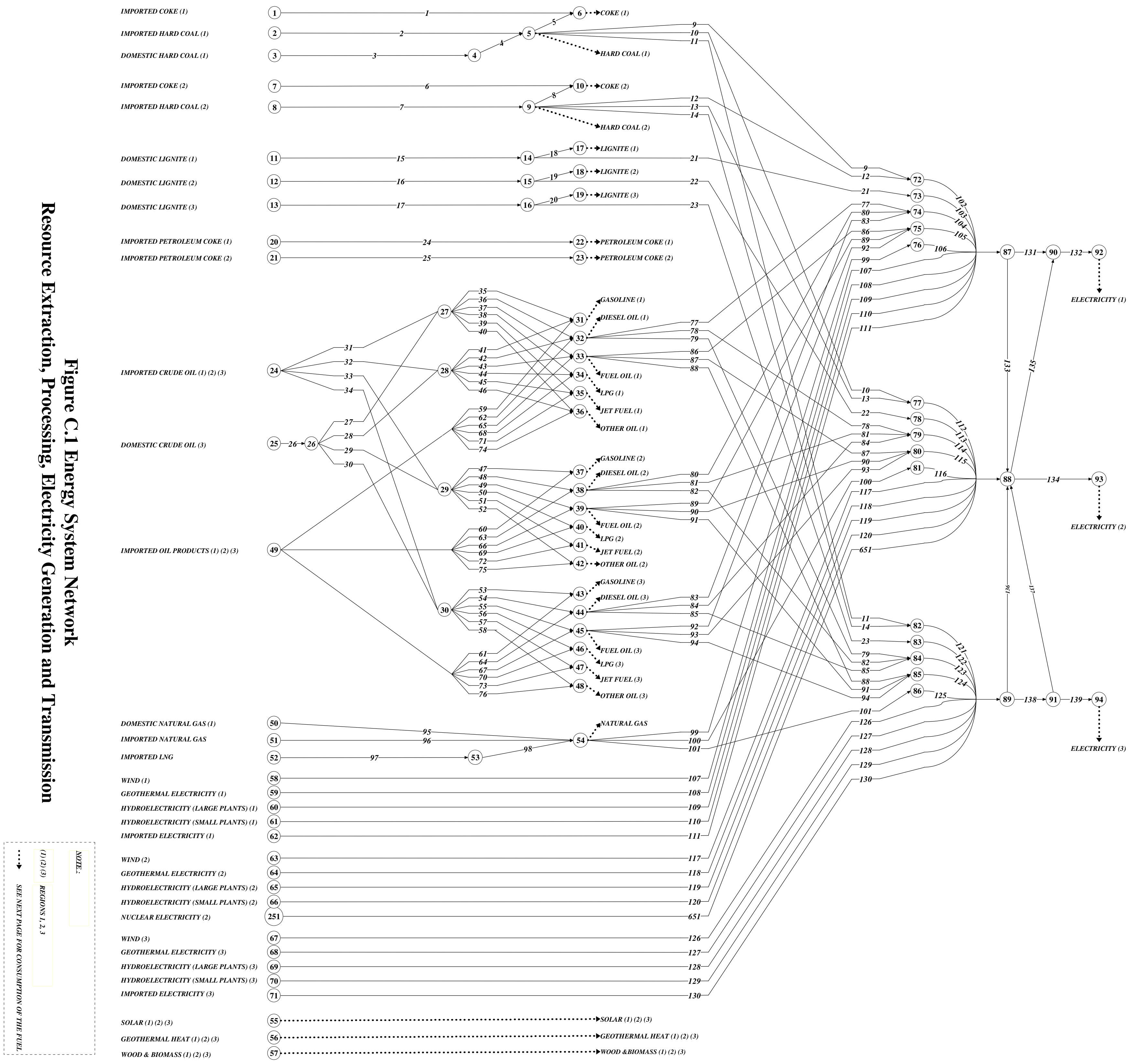
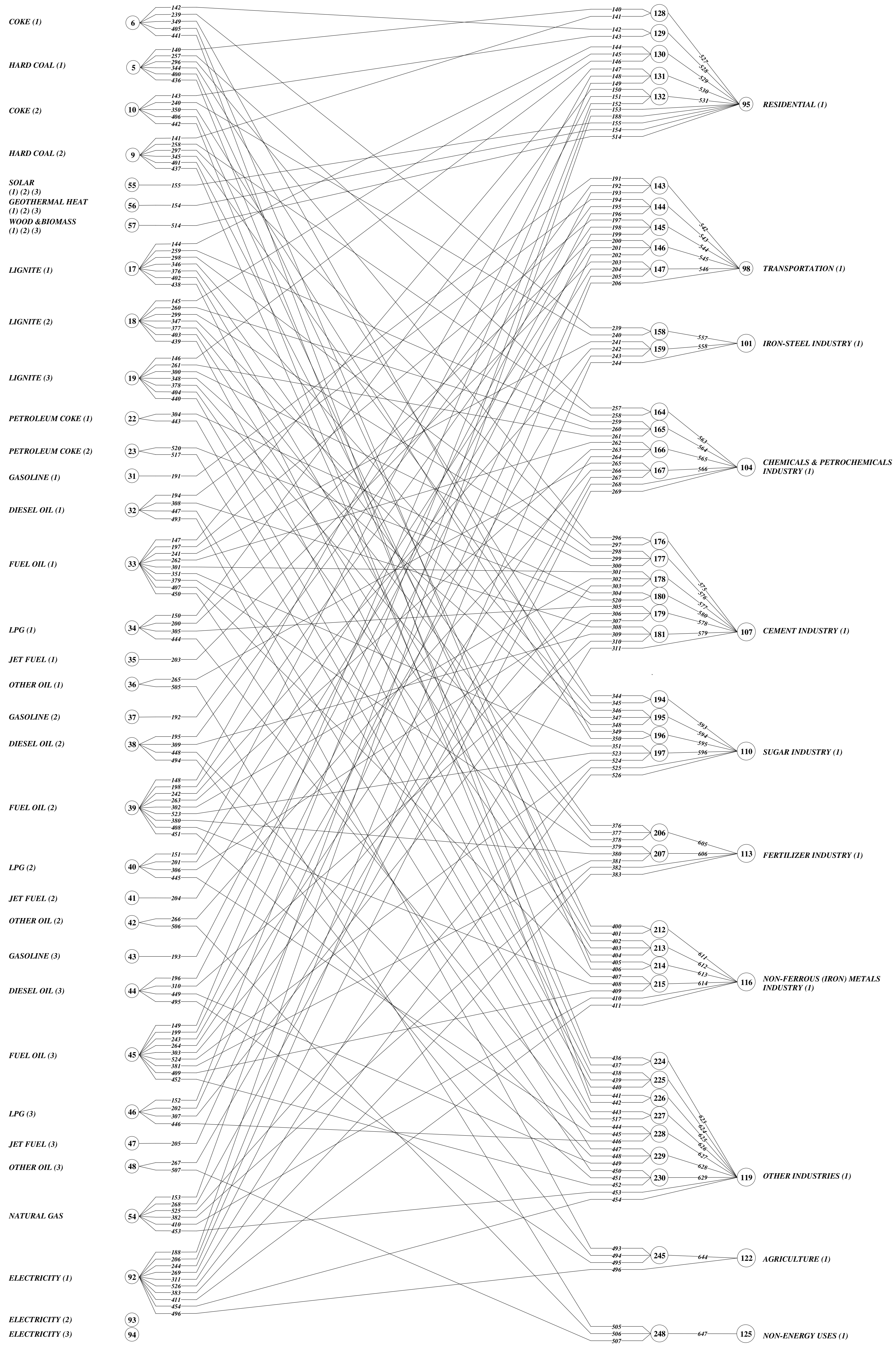


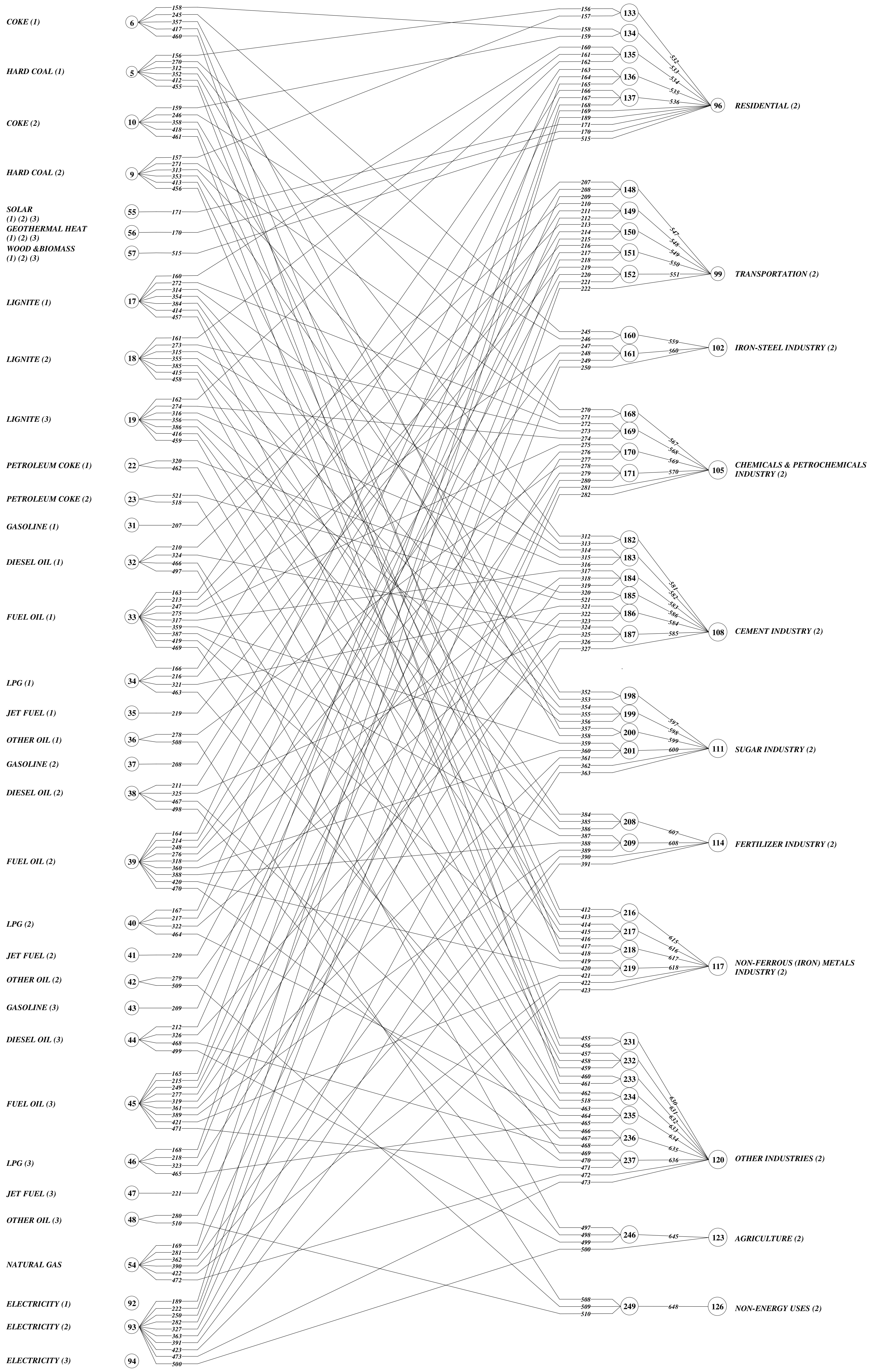
Figure C.1 Energy System Network
Resource Extraction, Processing, Electricity Generation and Transmission

Figure C.2 Energy System Network
Transportation, Distribution and Consumption in Region 1



NOTE:
(1) (2) (3) denote REGIONS 1, 2 and 3, respectively
Left side is grouped by energy sources and the right side is grouped by demand sectors. Every arc from sources to sectors is numbered both at the source side and at the sector side for convenience

Figure C.3 Energy System Network
Transportation, Distribution and Consumption in Region 2



NOTE:

(1) (2) (3) denote REGIONS 1, 2 and 3, respectively

Left side is grouped by energy sources and the right side is grouped by demand sectors. Every arc from sources to sectors is numbered both at the source side and at the sector side for convenience

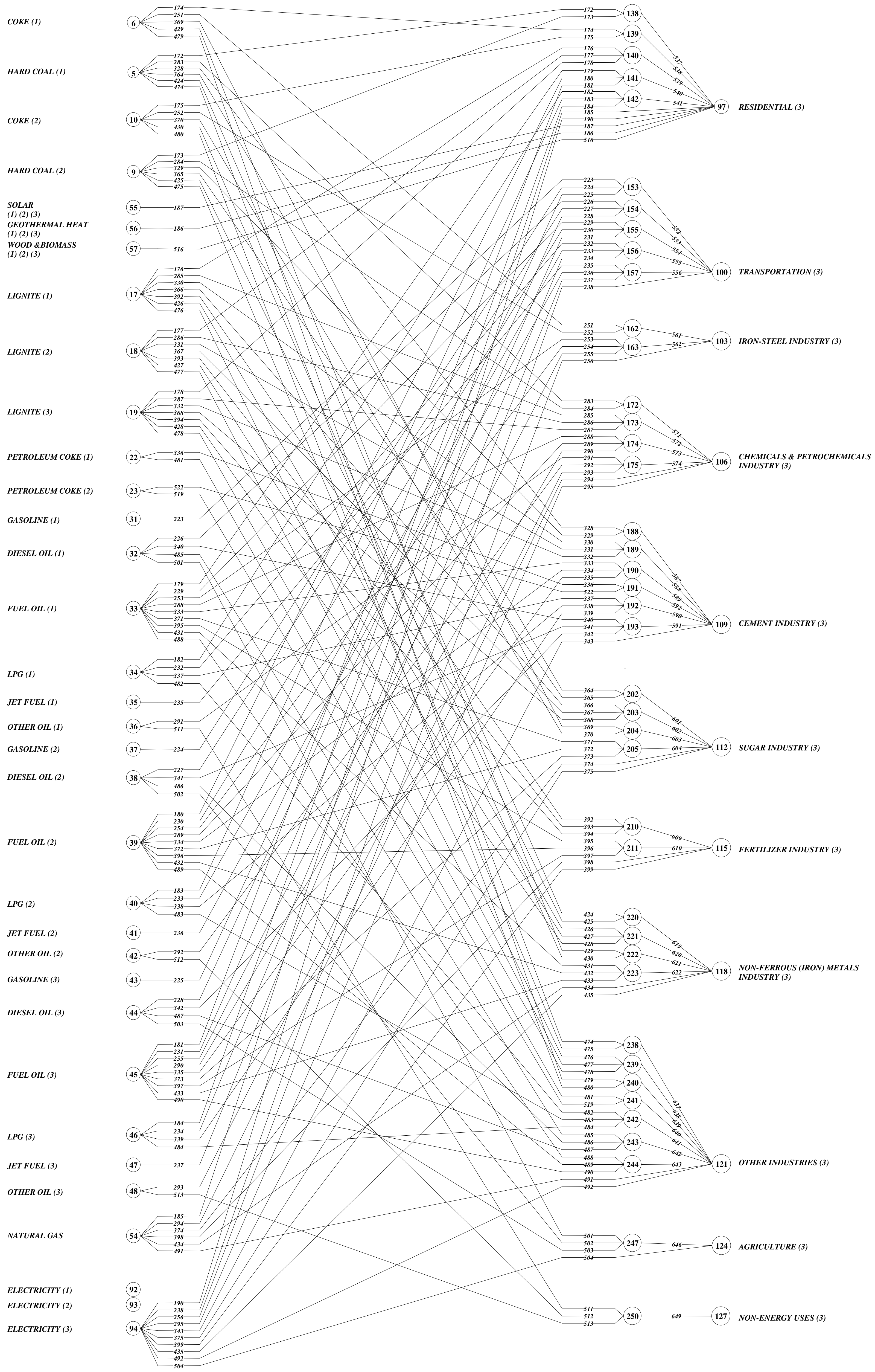


Figure C.4 Energy System Network
Transportation, Distribution and Consumption in Region 3

NOTE:
(1) (2) (3) denote REGIONS 1, 2 and 3, respectively
Left side is grouped by energy sources and the right side is grouped by demand sectors.
Every arc from sources to sectors is numbered both at the source side and at the sector side for convenience

D.2 Efficiencies

Table D.4 summarizes the efficiency parameters for the arcs whose efficiency parameter is different from 1. For the other ones the parameter is, by default, 1.

Table D.4 Efficiencies of the Activities (sources: [43], [47], [50], self calculation)

Arc	Efficiency	Arc	Efficiency	Arc	Efficiency	Arc	Efficiency
A005	0.7684	**A177**	0.9363	**A291**	0.9409	**A404**	0.8106
A008	0.7684	**A178**	0.9995	**A292**	0.9674	**A405**	0.9865
A010	0.9728	**A179**	0.9409	**A293**	0.989	**A406**	0.9761
A011	0.9653	**A180**	0.9674	**A294**	0.9697	**A407**	0.9908
A012	0.9761	**A181**	0.989	**A295**	0.93	**A408**	0.9639
A014	0.9755	**A182**	0.9498	**A296**	0.9864	**A409**	0.9427
A018	0.68	**A183**	0.9723	**A297**	0.9761	**A410**	0.9697
A019	0.68	**A184**	0.9907	**A298**	0.9648	**A411**	0.93
A027	0.9861	**A185**	0.9697	**A299**	0.9379	**A412**	0.9729
A028	0.99	**A186**	0.8	**A300**	0.8106	**A413**	0.9832
A029	0.9928	**A188**	0.93	**A301**	0.9908	**A414**	0.9295
A035	0.937	**A189**	0.93	**A302**	0.9639	**A415**	0.9564
A036	0.937	**A190**	0.93	**A303**	0.9427	**A416**	0.8518
A037	0.937	**A191**	0.9918	**A304**	0.9886	**A417**	0.9729
A038	0.937	**A192**	0.9676	**A305**	0.9922	**A418**	0.9832
A039	0.937	**A193**	0.9486	**A306**	0.9693	**A419**	0.9617
A040	0.937	**A194**	0.9915	**A307**	0.9513	**A420**	0.9886
A041	0.913	**A195**	0.9665	**A308**	0.9915	**A421**	0.9671
A042	0.913	**A196**	0.9468	**A309**	0.9665	**A422**	0.9697
A043	0.913	**A197**	0.9908	**A310**	0.9468	**A423**	0.93
A044	0.913	**A198**	0.9639	**A311**	0.93	**A424**	0.9653
A045	0.913	**A199**	0.9427	**A312**	0.9729	**A425**	0.9755
A046	0.913	**A200**	0.9922	**A313**	0.9832	**A426**	0.9098
A047	0.918	**A201**	0.9693	**A314**	0.9295	**A427**	0.9363
A048	0.918	**A202**	0.9513	**A315**	0.9564	**A428**	0.9995
A049	0.918	**A203**	0.9917	**A316**	0.8518	**A429**	0.9653
A050	0.918	**A204**	0.9675	**A317**	0.9617	**A430**	0.9755
A051	0.918	**A205**	0.9483	**A318**	0.9886	**A431**	0.9409
A052	0.918	**A206**	0.93	**A319**	0.9671	**A432**	0.9674
A053	0.93	**A207**	0.9656	**A320**	0.9523	**A433**	0.989
A054	0.93	**A208**	0.9898	**A321**	0.9675	**A434**	0.9697
A055	0.93	**A209**	0.9704	**A322**	0.9903	**A435**	0.93
A056	0.93	**A210**	0.9645	**A323**	0.972	**A436**	0.9865
A057	0.93	**A211**	0.9895	**A324**	0.9645	**A437**	0.9761
A058	0.93	**A212**	0.9694	**A325**	0.9895	**A438**	0.9648
A077	0.9915	**A213**	0.9617	**A326**	0.9694	**A439**	0.9379
A078	0.9645	**A214**	0.9886	**A327**	0.93	**A440**	0.8106
A079	0.9452	**A215**	0.9671	**A328**	0.9653	**A441**	0.9865
A080	0.9665	**A216**	0.9675	**A329**	0.9755	**A442**	0.9761
A081	0.9895	**A217**	0.9903	**A330**	0.9098	**A443**	0.9886
A082	0.9698	**A218**	0.972	**A331**	0.9363	**A444**	0.9922

Table D.4 (continued)

Arc	Efficiency	Arc	Efficiency	Arc	Efficiency	Arc	Efficiency
A083	0.9468	**A219**	0.9655	**A332**	0.9995	**A445**	0.9683
A084	0.9694	**A220**	0.9898	**A333**	0.9409	**A446**	0.9513
A085	0.9898	**A221**	0.9703	**A334**	0.9674	**A447**	0.9915
A086	0.9908	**A222**	0.93	**A335**	0.989	**A448**	0.9665
A087	0.9617	**A223**	0.947	**A336**	0.9263	**A449**	0.9468
A088	0.9409	**A224**	0.9708	**A337**	0.9498	**A450**	0.9908
A089	0.9639	**A225**	0.9902	**A338**	0.9723	**A451**	0.9639
A090	0.9886	**A226**	0.9452	**A339**	0.9907	**A452**	0.9427
A091	0.9674	**A227**	0.9698	**A340**	0.9452	**A453**	0.9697
A092	0.9427	**A228**	0.9898	**A341**	0.9698	**A454**	0.93
A093	0.9671	**A229**	0.9409	**A342**	0.9898	**A455**	0.9729
A094	0.989	**A230**	0.9674	**A343**	0.93	**A456**	0.9832
A099	0.9697	**A231**	0.989	**A344**	0.9865	**A457**	0.9295
A100	0.9697	**A232**	0.9498	**A345**	0.9761	**A458**	0.9564
A101	0.9697	**A233**	0.9723	**A346**	0.9648	**A459**	0.8518
A102	0.407	**A234**	0.9907	**A347**	0.9379	**A460**	0.9729
A103	0.402	**A235**	0.9467	**A348**	0.8106	**A461**	0.9832
A104	0.339	**A236**	0.9706	**A349**	0.9865	**A462**	0.9523
A105	0.377	**A237**	0.9901	**A350**	0.9761	**A463**	0.9675
A106	0.494	**A238**	0.93	**A351**	0.9908	**A464**	0.9903
A112	0.407	**A239**	0.9865	**A352**	0.9729	**A465**	0.972
A113	0.402	**A240**	0.9761	**A353**	0.9832	**A466**	0.9645
A114	0.339	**A241**	0.9908	**A354**	0.9295	**A467**	0.9895
A115	0.377	**A242**	0.9639	**A355**	0.9564	**A468**	0.9694
A116	0.494	**A243**	0.9427	**A356**	0.8518	**A469**	0.9617
A121	0.407	**A244**	0.93	**A357**	0.9729	**A470**	0.9886
A122	0.402	**A245**	0.9729	**A358**	0.9832	**A471**	0.9671
A123	0.339	**A246**	0.9832	**A359**	0.9617	**A472**	0.9697
A124	0.377	**A247**	0.9617	**A360**	0.9886	**A473**	0.93
A125	0.494	**A248**	0.9886	**A361**	0.9671	**A474**	0.9653
A132	0.99	**A249**	0.9671	**A362**	0.9697	**A475**	0.9755
A133	0.98	**A250**	0.93	**A363**	0.93	**A476**	0.9098
A134	0.99	**A251**	0.9653	**A364**	0.9653	**A477**	0.9363
A135	0.98	**A252**	0.9755	**A365**	0.9755	**A478**	0.9995
A136	0.98	**A253**	0.9409	**A366**	0.9098	**A479**	0.9653
A137	0.98	**A254**	0.9674	**A367**	0.9363	**A480**	0.9755
A139	0.99	**A255**	0.989	**A368**	0.9995	**A481**	0.9263
A140	0.9865	**A256**	0.93	**A369**	0.9653	**A482**	0.9498
A141	0.976	**A257**	0.9865	**A370**	0.9755	**A483**	0.9723
A142	0.9865	**A258**	0.9761	**A371**	0.9409	**A484**	0.9907
A143	0.976	**A259**	0.9648	**A372**	0.9674	**A485**	0.9452
A144	0.9648	**A260**	0.9379	**A373**	0.989	**A486**	0.9698
A145	0.9379	**A261**	0.8106	**A374**	0.9697	**A487**	0.9898
A146	0.8106	**A262**	0.9908	**A375**	0.93	**A488**	0.9409
A147	0.9908	**A263**	0.9639	**A376**	0.948	**A489**	0.9674
A148	0.9639	**A264**	0.9427	**A377**	0.9379	**A490**	0.989
A149	0.9427	**A265**	0.9908	**A378**	0.8106	**A491**	0.9697
A150	0.9922	**A266**	0.9639	**A379**	0.9908	**A492**	0.93
A151	0.9693	**A267**	0.9427	**A380**	0.9639	**A493**	0.9915
A152	0.9513	**A268**	0.9697	**A381**	0.9427	**A494**	0.9665

Table D.4 (continued)

Arc	Efficiency	Arc	Efficiency	Arc	Efficiency	Arc	Efficiency
A153	0.9697	**A269**	0.93	**A382**	0.9697	**A495**	0.9468
A154	0.8	**A270**	0.9729	**A383**	0.93	**A496**	0.93
A156	0.9729	**A271**	0.9832	**A384**	0.9295	**A497**	0.9645
A157	0.9832	**A272**	0.9295	**A385**	0.9564	**A498**	0.9895
A158	0.9729	**A273**	0.9564	**A386**	0.8518	**A499**	0.9694
A159	0.9832	**A274**	0.8518	**A387**	0.9617	**A500**	0.93
A160	0.9295	**A275**	0.9617	**A388**	0.9886	**A501**	0.9452
A161	0.9563	**A276**	0.9886	**A389**	0.9671	**A502**	0.9698
A162	0.8518	**A277**	0.9671	**A390**	0.9697	**A503**	0.9898
A163	0.9617	**A278**	0.9617	**A391**	0.93	**A504**	0.93
A164	0.9886	**A279**	0.9886	**A392**	0.9098	**A517**	0.955
A165	0.9671	**A280**	0.9671	**A393**	0.9363	**A518**	0.9858
A166	0.9675	**A281**	0.9697	**A394**	0.9995	**A519**	0.9594
A167	0.9903	**A282**	0.93	**A395**	0.9409	**A520**	0.955
A168	0.972	**A283**	0.9653	**A396**	0.9674	**A521**	0.9858
A169	0.9697	**A284**	0.9755	**A397**	0.989	**A522**	0.9594
A170	0.8	**A285**	0.9098	**A398**	0.9697	**A523**	0.9639
A172	0.9653	**A286**	0.9363	**A399**	0.93	**A524**	0.9427
A173	0.9755	**A287**	0.9995	**A400**	0.9865	**A525**	0.9697
A174	0.9653	**A288**	0.9409	**A401**	0.9761	**A526**	0.93
A175	0.9755	**A289**	0.9674	**A402**	0.9648		
A176	0.9098	**A290**	0.989	**A403**	0.9379		

The efficiencies of coal facilities were taken from MENR [43]. The electricity generation, transmission and distribution efficiencies are from TEİAŞ [47]. Electricity generation from renewable resources and nuclear energy has an efficiency value of 1 as the flows through these arcs were defined as electricity as they include, in our model, no fuel to electricity conversion. The efficiencies of geothermal heating were taken from DPT [50]. Finally the remaining transportation efficiencies were calculated as explained below.

In order to calculate the transportation efficiencies we used the energy efficiencies of transport modes in BTU per ton mile [51] [52]. The Table D.5 summarizes these. After these, we used the unit calorific contents of the transported fuels in order to determine how much energy a ton of the transported good carries. Then we multiplied the two, with the estimated transportation distance to find the efficiency of transportation activity. See formula (40) for the calculation of arc efficiency (e) from efficiency of freight modes (me), calorific content (unitcal) and transportation distance (dist).

$$e = (me \times 0.252 / 1.609) \times (unitcal \times 1000) \times (edist) \quad (40)$$
$$\qquad \textit{(kcal/ton.km)} \qquad \textit{(kcal/ton)} \qquad \textit{(km)}$$

Table D.5 Energy Efficiencies of Freight Modes

Mode	Efficiency *(BTU / ton.mile)*	Mode	Efficiency *(BTU / ton.mile)*
Rail	890	Natural gas pipe	2000
Truck	3420	Marine	420
Oil pipe	500		

Transportation distances within each region are estimated as follows: the transportation is assumed to be from the regional center to each city, for every region the center of gravity is found according to the populations of each city in that region and weighted average of the distance (Euclidean) is found from that center to each city in the region. For interregional transportation the activity is assumed to start at a regional center, followed by transportation to another center and finally transportation within the destination region. Table D.6 shows the estimated distances within each region and between regions. The exceptions to this scheme are natural gas and domestic oil. Since the natural gas is taken as a country wide network without differentiating interregional transportations, a single efficiency for the transportation of natural gas through gas pipelines is used, which is 96.97% [52]. Transportation of domestic oil from Region 3 to other regons is found by a combination of pipeline and marine transportation. The domestic oil is transported to Ceyhan with a 511 km pipeline. Then it is transported to İzmit and İzmir with marine transportation on an estimated distance of 1613 and 995 km, respectively, and to Kırıkkale by another pipeline with a length of 448 km.

Table D.6 Estimated Transportation Distances

From	To 1	2	3
1	164.42	686.54	1059.67
2	647.30	203.66	583.71
3	1027.37	590.65	196.73

D.3 Activity Costs

The activity costs related with domestic resources, conversion facilities and transportation are assumed to be unchanged durng the planning horizon. On the other hand price projections for imported goods like oil and oil products, natural gas and LNG, and hard coal and coke are used.

For coal import costs[1], projections in [53] [54] and [55] are used after converting to 2003 dollars[2]. The projections were given for OECD average. That is why a comparison between average costs for Turkey and the average of OECD was made based on the past 10 years data in [56] and [57]. As a result Turkish costs were found to be (0.982 x OECD Average) for hard coal, and for coke the cost was 1.44 times the hard coal cost. For domestic coal (hard coal and lignite), the 2003 costs for extraction and processing were obtained from MENR[3] [43], during the preparations of Turkey’s initial national communication to the UNFCCC. The hard coal extraction and cleaning information is supplied by TTK, coking information by İskenderun Iron and Steel Factory and the lignite extraction and cleaning information is supplied by TKİ.

[1] All import costs are CIF costs; including cost, insurance and freight to national ports.
[2] All projections were converted to 2003 dollars.
[3] Similarly, much of the cost information on other fuels was obtained from MENR. These were a compilation of correspondences between MENR and certain other institutions. Since MENR is the source from which we obtained the information the references will include MENR, however here the original source will be mentioned, too.

The domestic crude oil costs were obtained from [43]. The transportation costs and oil refining costs in them were supplied by TÜPRAŞ. Imported crude oil was treated similar to hard coal and coke. The projections in [53], [54] and [55] were used for the “IEA average”. Therefore the data for previous years in [56] and [58] was used to relate Turkish crude oil import cost IEA average and to relate refined oil products’ import costs to the crude oil cost. Then the import costs of gasoline, diesel oil, LPG, jet fuel, fuel oil and other oil is assumed to be 1.28, 1.25, 1.3, 1.32, 0.81 and 1.06 times the cost of crude oil. Finally the cost of importing crude oil to Kırıkkale includes the cost of pipeline transportation cost of 2.94 $/ton in addition to the cost of crude oil import.

For natural gas, again, the same way is followed. The projections in [53], [54] and [55] were for Europe for natural gas andfor Japan for LNG. The natural gas import cost for Turkey is assumed to be equal to European average and the Japanese LNG import cost is related to this natural gas cost based on past data in [49] and [56]. Then the LNG import cost to Europe is assumed to be 0.74 times the cost of Japanese LNG import cost. The costs of domestic production, LNG gasification and overall transportation are obtained from MENR [43] and the provider of these transportation costs is BOTAŞ.

Electricity generation, transmission and distribution costs were obtained from TEİAŞ [59]. The cost of wood and biomass is obtained from DPT [60]. Table D.7 lists the costs which are held constant over time and Table D.8 lists the projections used in the model. The units are shown with asterisks; costs are in \$/ton (*), \$/m^3 (**), \$/kWh (***) or \$/toe (****). The costs which are not mentioned in these lists are assumed to be zero. Note that cost of refining fuel oil is negative meaning that this oil is residual and its cost is declared less than the cost of crude oil by TÜPRAŞ.

Table D.7 Activity Costs

Arc	Cost	Arc	Cost	Arc	Cost	Arc	Cost
A003*	128.27	**A051***	40.16	**A122*****	0.01326	**A362****	0.01632
A004*	4.20	**A052***	-46.54	**A123*****	0.00678	**A363*****	0.0235
A005*	14.71	**A053***	113.04	**A124*****	0.00226	**A374****	0.01632
A008*	14.71	**A054***	63.81	**A125*****	0.00143	**A375*****	0.0235
A015*	15.52	**A055***	-41.09	**A126*****	0.04150	**A382****	0.01632
A016*	24.94	**A056***	155.93	**A127*****	0.02257	**A383*****	0.0235
A017*	8.88	**A057***	146.93	**A128*****	0.00291	**A390****	0.01632
A018*	5.93	**A058***	-9.72	**A129*****	0.00291	**A391*****	0.0235
A019*	5.93	**A095****	0.00764	**A132*****	0.00354	**A398****	0.01632
A020*	5.93	**A098****	0.01551	**A134*****	0.00354	**A399*****	0.0235
A024*	37.78	**A099****	0.01632	**A139*****	0.00354	**A410****	0.01632
A025*	37.78	**A100****	0.01632	**A153****	0.01632	**A411*****	0.0235
A026*	32.92	**A101****	0.01632	**A169****	0.01632	**A422****	0.01632
A027*	5.56	**A102*****	0.00836	**A185****	0.01632	**A423*****	0.0235
A028*	3.72	**A103*****	0.01326	**A188*****	0.0235	**A434****	0.01632
A029*	7.62	**A104*****	0.00678	**A189*****	0.0235	**A435*****	0.0235
A035*	78.29	**A105*****	0.00226	**A190*****	0.0235	**A453****	0.01632
A036*	44.49	**A106*****	0.00143	**A206*****	0.0235	**A454*****	0.0235
A037*	-55.93	**A107*****	0.04150	**A222*****	0.0235	**A472****	0.01632
A038*	104.95	**A108*****	0.02257	**A238*****	0.0235	**A473*****	0.0235
A039*	50.99	**A109*****	0.00291	**A244*****	0.0235	**A491****	0.01632
A040*	-3.95	**A110*****	0.00291	**A250*****	0.0235	**A492*****	0.0235
A041*	56.92	**A112*****	0.00836	**A256*****	0.0235	**A496*****	0.0235
A042*	27.72	**A113*****	0.01326	**A268****	0.01632	**A500*****	0.0235
A043*	-72.92	**A114*****	0.00678	**A269*****	0.0235	**A504*****	0.0235
A044*	77.81	**A115*****	0.00226	**A281****	0.01632	**A514***	28.23
A045*	22.8	**A116*****	0.00143	**A282*****	0.0235	**A515***	28.23
A046*	-22.77	**A117*****	0.04150	**A294****	0.01632	**A516***	28.23
A047*	69.72	**A118*****	0.02257	**A295*****	0.0235	**A525****	0.01632
A048*	33.26	**A119*****	0.00291	**A311*****	0.0235	**A526*****	0.0235
A049*	-60.76	**A120*****	0.00291	**A327*****	0.0235	**A650*****	0.01727
A050*	89.54	**A121*****	0.00836	**A343*****	0.0235		

Table D.8 Activity Costs, Projections

	2003	2004	2005	2006	2007	2008	2009	2010
A001*	58.68	77.42	85.94	83.89	81.84	79.79	77.74	75.69
A002*	40.75	53.76	59.68	58.25	56.83	55.41	53.98	52.56
A006*	58.68	77.42	85.94	83.89	81.84	79.79	77.74	75.69
A007*	40.75	53.76	59.68	58.25	56.83	55.41	53.98	52.56
A031*	198.39	258.98	356.01	357.24	358.48	359.72	360.96	362.19
A032*	199.48	258.98	356.01	357.24	358.48	359.72	360.96	362.19
A033*	205.65	261.92	358.94	360.18	361.42	362.66	363.89	365.13
A034*	191.37	258.98	356.01	357.24	358.48	359.72	360.96	362.19
A059*	272.74	331.5	455.69	457.27	458.86	460.44	462.02	463.61
A060*	272.74	331.5	455.69	457.27	458.86	460.44	462.02	463.61
A061*	272.74	331.5	455.69	457.27	458.86	460.44	462.02	463.61
A062*	266.35	323.73	445.01	446.55	448.1	449.65	451.2	452.74
A063*	266.35	323.73	445.01	446.55	448.1	449.65	451.2	452.74
A064*	266.35	323.73	445.01	446.55	448.1	449.65	451.2	452.74
A065*	172.6	209.77	288.36	289.37	290.37	291.37	292.37	293.38
A066*	172.6	209.77	288.36	289.37	290.37	291.37	292.37	293.38
A067*	172.6	209.77	288.36	289.37	290.37	291.37	292.37	293.38
A068*	277.01	336.67	462.81	464.42	466.03	467.63	469.24	470.85
A069*	277.01	336.67	462.81	464.42	466.03	467.63	469.24	470.85
A070*	277.01	336.67	462.81	464.42	466.03	467.63	469.24	470.85
A071*	281.27	341.85	469.93	471.56	473.19	474.83	476.46	478.1
A072*	281.27	341.85	469.93	471.56	473.19	474.83	476.46	478.1
A073*	281.27	341.85	469.93	471.56	473.19	474.83	476.46	478.1
A074*	225.87	274.52	377.37	378.68	379.99	381.3	382.61	383.93
A075*	225.87	274.52	377.37	378.68	379.99	381.3	382.61	383.93
A076*	225.87	274.52	377.37	378.68	379.99	381.3	382.61	383.93
A096**	0.13978	0.15098	0.20313	0.20426	0.20538	0.20651	0.20763	0.20876
A097**	0.14415	0.13833	0.15786	0.16072	0.16358	0.16644	0.1693	0.17216

Table D.8 (continued)

	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
A001*	75.8	75.91	76.02	76.13	76.24	76.35	76.46	76.57	76.68	76.79
A002*	52.64	52.71	52.79	52.87	52.94	53.02	53.09	53.17	53.25	53.32
A006*	75.8	75.91	76.02	76.13	76.24	76.35	76.46	76.57	76.68	76.79
A007*	52.64	52.71	52.79	52.87	52.94	53.02	53.09	53.17	53.25	53.32
A031*	359.59	356.99	354.39	351.79	349.18	346.58	343.98	341.38	338.77	336.17
A032*	359.59	356.99	354.39	351.79	349.18	346.58	343.98	341.38	338.77	336.17
A033*	362.53	359.93	357.32	354.72	352.12	349.52	346.92	344.31	341.71	339.11
A034*	359.59	356.99	354.39	351.79	349.18	346.58	343.98	341.38	338.77	336.17
A059*	460.28	456.95	453.62	450.29	446.95	443.62	440.29	436.96	433.63	430.3
A060*	460.28	456.95	453.62	450.29	446.95	443.62	440.29	436.96	433.63	430.3
A061*	460.28	456.95	453.62	450.29	446.95	443.62	440.29	436.96	433.63	430.3
A062*	449.49	446.24	442.98	439.73	436.48	433.23	429.97	426.72	423.47	420.22
A063*	449.49	446.24	442.98	439.73	436.48	433.23	429.97	426.72	423.47	420.22
A064*	449.49	446.24	442.98	439.73	436.48	433.23	429.97	426.72	423.47	420.22
A065*	291.27	289.16	287.05	284.95	282.84	280.73	278.62	276.52	274.41	272.3
A066*	291.27	289.16	287.05	284.95	282.84	280.73	278.62	276.52	274.41	272.3
A067*	291.27	289.16	287.05	284.95	282.84	280.73	278.62	276.52	274.41	272.3
A068*	467.47	464.09	460.7	457.32	453.94	450.56	447.17	443.79	440.41	437.02
A069*	467.47	464.09	460.7	457.32	453.94	450.56	447.17	443.79	440.41	437.02
A070*	467.47	464.09	460.7	457.32	453.94	450.56	447.17	443.79	440.41	437.02
A071*	474.66	471.23	467.79	464.36	460.92	457.49	454.05	450.62	447.18	443.75
A072*	474.66	471.23	467.79	464.36	460.92	457.49	454.05	450.62	447.18	443.75
A073*	474.66	471.23	467.79	464.36	460.92	457.49	454.05	450.62	447.18	443.75
A074*	381.17	378.41	375.65	372.89	370.13	367.38	364.62	361.86	359.1	356.34
A075*	381.17	378.41	375.65	372.89	370.13	367.38	364.62	361.86	359.1	356.34
A076*	381.17	378.41	375.65	372.89	370.13	367.38	364.62	361.86	359.1	356.34
A096**	0.2074	0.2060	0.2046	0.2033	0.2019	0.2005	0.1992	0.1978	0.1964	0.1951
A097**	0.1707	0.1691	0.1676	0.1661	0.1646	0.1631	0.1616	0.1601	0.1586	0.1571

D.4 Capacities and Investment Costs

The capacity and reserce data is obtained from different resources: hard coal capacity and reserves from [44], lignite capacities from [46], lignite reserves from [61], crude oil and natural gas capacities and reserves from [62] and wood and biomass capacities from [60]. Geothermal capacities are from [50] and they are distributed to regions according to the geothermal inventory prepared by MTA [61]. Hydroelectricity capacities are obtained from TEİAŞ [47]. The capacity of LNG gasification facility is taken from [49]. The capacity expansion costs below are taken from [63]. Table D.9 shows the capacities of the capacitated arcs, investment costs and associated reserves, if any. Note that reserves for renewable resources like geothermal and hydroelectricity (small plants as the rest are modeled as projects) have annual potentials. The ones with the asterisks are already explained under power plant capacities. Here, they are included to show their reserves (maximum annual potentials).

Table D.9 Arc Capacities, Reserves and Corresponding Units

	Capacity	Investment Cost	Reserve
A003	4,750,000 ton	4.50 $ / ton /yr	1,331,000,000 ton
A015	50,972,000 ton	0.60 $ / ton /yr	3,065,848,000 ton
A016	6,020,000 ton	0.60 $ / ton /yr	1,510,959,000 ton
A017	21,955,000 ton	0.60 $ / ton /yr	3,801,368,000 ton
A026	2,375,000 ton	204.00 $ / ton /yr	42,756,379 ton
A095	560,000,000 m3	0.25 $ / m3 / yr	7,951,737,541 m3
A098	6,300,000,000 m3	0.09 $ / m3 / yr	-
A110*			2201 kwh / yr
A120*			4724 kwh / yr
A129*			8930 kwh / yr
A154	1440 MWt	250,000 $ / MWt	27229 MWt / yr
A155	201600 toe	-	-
A170	690 MWt	250,000 $ / MWt	2988 MWt / yr
A171	96705 toe	-	-
A186	369 MWt	250,000 $ / MWt	1282 MWt / yr
A187	51660 toe	-	-
A514	14400000 ton	-	59,205,347 ton
A515	6907500 ton	-	50,227,564 ton
A516	3690000 ton	-	103,900,688 ton

The costs of electricity investment were separated from the other capacitated arcs. Table D.10 presents the investment costs for the aggregated plant types tha are shown by arcs in the network. Note that investment cost is defined as linear variable, fixed plus linear variable or as project costs for different plant types. The data is from TEİAŞ [47] except oil plants, which are from IEA [64].

Table D.10 Power Plant Properties, Capacities and Investment Costs

Arc	Fuel	Plant Factor	Initial Capacity *(MW)*	Investment Cost Variable *($/MW)*	
A104	Diesel	0.75	189	1,340,000	
A114			2		
A123			44		
A105	Fuel Oil	0.75	1,456	1,340,000	
A115			477		
A124			569		
A107	Wind	0.4	17	1,250,000	
A117			0		
A126			0		
A108	Geothermal	0.7	15	2,500,000	
A118			0		
A127			0		
A110	Hydro Small	0.5	184	1,207,000	
A120			281		
A129			230		
				Fixed *($)*	**Variable** *($/MW)*
A102	Hard Coal	0.75	480	58,679,000	1,026,000
A112			1,320		
A121			0		
A103	Lignite	0.75	4,095	2,056,000	1,390,000
A113			979		
A122			1,831		
A106	Natural Gas	0.8	11,148	72,537,000	502,000
A116			357		
A125			0		
				Project Cost *($)*	
A109	Hydro Large	0.4	1,201	*See Table 3.16 for individual projects*	
A119			2,950		
A128			7,733		
A650	Nuclear	0.8	0	2,625,000,000	

D.5 Emissions

The model calculates the resulting emissions for six gases. The unit emission quantities in kg/GJ are tabulated in Table D.11 below. These emissions data is obtained from the previous study [39]. Refinery emissions are found based on the fuel oil and refineray gas they consume per output.

Table D.11 Emission Factors

	CH4	CO	CO2	N2O	NOX	SO2
A027	0.000112	0.000707	3.9112	0.000134	0.006654	0.086084
A028	0.000174	0.000972	5.22704	0.0001	0.009933	0.024724
A029	0.000153	0.000912	4.99069	0.000136	0.008937	0.019978
A030	0.000141	0.000705	3.68064	0.000014	0.00776	0.022505
A031	0.000112	0.000707	3.9112	0.000134	0.006654	0.086084
A032	0.000174	0.000972	5.22704	0.0001	0.009933	0.024724
A033	0.000153	0.000912	4.99069	0.000136	0.008937	0.019978
A034	0.000141	0.000705	3.68064	0.000014	0.00776	0.022505
A102	0.001	0.02	92.708	0.0014	0.23	1.24
A103	0.001	0.02	99.176	0.0014	0.17	3.07
A104	0.003	0.015	73.33	0.0006	0.2	0.0463
A105	0.003	0.015	76.59	0.0006	0.2	1.99
A106	0.001	0.02	55.8195	0.0001	0.039	0.0058
A112	0.001	0.02	92.708	0.0014	0.23	1.24
A113	0.001	0.02	99.176	0.0014	0.17	3.07
A114	0.003	0.015	73.33	0.0006	0.2	0.0463
A115	0.003	0.015	76.59	0.0006	0.2	1.99
A116	0.001	0.02	55.8195	0.0001	0.039	0.0058
A121	0.001	0.02	92.708	0.0014	0.23	1.24
A122	0.001	0.02	99.176	0.0014	0.1737	4.0325
A123	0.003	0.015	73.33	0.0006	0.2	0.0463
A124	0.003	0.015	76.59	0.0006	0.2	1.99
A125	0.001	0.02	55.8195	0.0001	0.039	0.0058
A153	0.0010308	0.017928	55.8195	0.00098602	0.04213	0.00026891
A169	0.0010308	0.017928	55.8195	0.00098602	0.04213	0.00026891
A185	0.0010308	0.017928	55.8195	0.00098602	0.04213	0.00026891
A268	0.0010308	0.037648	55.8195	0.00098602	0.12549	0.00026891
A281	0.0010308	0.037648	55.8195	0.00098602	0.12549	0.00026891
A294	0.0010308	0.037648	55.8195	0.00098602	0.12549	0.00026891
A362	0.0010726	0.039175	55.8195	0.001026	0.13058	0.00027982
A374	0.0010726	0.039175	55.8195	0.001026	0.13058	0.00027982
A382	0.0010667	0.038958	55.8195	0.0010203	0.12986	0.00027827
A390	0.0010667	0.038958	55.8195	0.0010203	0.12986	0.00027827

Table D.11 (continued)

	CH4	CO	CO2	N2O	NOX	SO2
A398	0.0010667	0.038958	55.8195	0.0010203	0.12986	0.00027827
A410	0.0010308	0.037648	55.8195	0.00098602	0.12549	0.00026891
A422	0.0010308	0.037648	55.8195	0.00098602	0.12549	0.00026891
A434	0.0010308	0.037648	55.8195	0.00098602	0.12549	0.00026891
A453	0.0010308	0.037648	55.8195	0.00098602	0.12549	0.00026891
A472	0.0010308	0.037648	55.8195	0.00098602	0.12549	0.00026891
A491	0.0010308	0.037648	55.8195	0.00098602	0.12549	0.00026891
A525	0.0010726	0.039175	55.8195	0.001026	0.13058	0.00027982
A527	0.094334	5.1884	92.708	0.001698	0.17169	0.58487
A528	0.096154	5.2885	92.708	0.0017308	0.175	0.59615
A529	0.11582	6.37	99.176	0.00092655	0.21079	0.71808
A530	0.0013947	0.014681	76.59	0.00014681	0.16149	0.46831
A531	0.0010094	0.010391	62.44	0.0044534	0.074224	0.000080162
A532	0.094334	5.1884	92.708	0.001698	0.17169	0.58487
A533	0.096154	5.2885	92.708	0.0017308	0.175	0.59615
A534	0.11582	6.37	99.176	0.00092655	0.21079	0.71808
A535	0.0013947	0.014681	76.59	0.00014681	0.16149	0.46831
A536	0.0010094	0.010391	62.44	0.0044534	0.074224	0.000080162
A537	0.094334	5.1884	92.708	0.001698	0.17169	0.58487
A538	0.096154	5.2885	92.708	0.0017308	0.175	0.59615
A539	0.11582	6.37	99.176	0.00092655	0.21079	0.71808
A540	0.0013947	0.014681	76.59	0.00014681	0.16149	0.46831
A541	0.0010094	0.010391	62.44	0.0044534	0.074224	0.000080162
A542	0.0252	6.5047	68.61	0.0024	0.787	0.0438
A543	0.0047	0.6486	73.33	0.0035	0.7078	0.4615
A544	0.0029361	0.014681	76.59	0.00032297	0.16149	0.46831
A545	0.0010094	0.010391	62.44	0.0044534	0.074224	0.000080162
A546	0.0005	0.14429	70.785	0.0020613	0.22674	0.0463
A547	0.0252	6.5047	68.61	0.0024	0.787	0.0438
A548	0.0047	0.6486	73.33	0.0035	0.7078	0.4615
A549	0.0029361	0.014681	76.59	0.00032297	0.16149	0.46831
A550	0.0010094	0.010391	62.44	0.0044534	0.074224	0.000080162
A551	0.0005	0.14429	70.785	0.0020613	0.22674	0.0463
A552	0.0252	6.5047	68.61	0.0024	0.787	0.0438
A553	0.0047	0.6486	73.33	0.0035	0.7078	0.4615
A554	0.0029361	0.014681	76.59	0.00032297	0.16149	0.46831
A555	0.0010094	0.010391	62.44	0.0044534	0.074224	0.000080162
A556	0.0005	0.14429	70.785	0.0020613	0.22674	0.0463
A557	0.0011538	0.11538	92.708	0.00076923	0.14423	0.73077
A558	0.0029361	0.014681	76.59	0.00032297	0.16149	0.46831
A559	0.0011538	0.11538	92.708	0.00076923	0.14423	0.73077
A560	0.0029361	0.014681	76.59	0.00032297	0.16149	0.46831
A561	0.0011538	0.11538	92.708	0.00076923	0.14423	0.73077
A562	0.0029361	0.014681	76.59	0.00032297	0.16149	0.46831
A563	0.001132	0.1132	92.708	0.00075467	0.1415	0.71694
A564	0.00007726	0.007082	99.176	0.0014	0.16431	0.84986
A565	0.0029361	0.014681	76.59	0.00032297	0.16149	0.46831
A566	0	0	0	0	0	0

Table D.11 (continued)

	CH4	CO	CO2	N2O	NOX	SO2
A567	0.001132	0.1132	92.708	0.00075467	0.1415	0.71694
A568	0.00007726	0.007082	99.176	0.0014	0.16431	0.84986
A569	0.0029361	0.014681	76.59	0.00032297	0.16149	0.46831
A570	0	0	0	0	0	0
A571	0.001132	0.1132	92.708	0.00075467	0.1415	0.71694
A572	0.00007726	0.007082	99.176	0.0014	0.16431	0.84986
A573	0.0029361	0.014681	76.59	0.00032297	0.16149	0.46831
A574	0	0	0	0	0	0
A575	0.001132	0.1132	92.708	0.00075467	0.1415	0.71694
A576	0.000090909	0.008333	99.176	0.0014	0.19333	1
A577	0.0031449	0.015724	76.59	0.00034594	0.17297	0.50161
A578	0.0010094	0.010391	62.44	0.0044534	0.074224	0.000080162
A579	0.00017345	0.016678	73.33	0.00036692	0.066713	0.482
A580	0.003871	0.019355	99.83	0.00042581	0.2129	0.61742
A581	0.001132	0.1132	92.708	0.00075467	0.1415	0.71694
A582	0.000090909	0.008333	99.176	0.0014	0.19333	1
A583	0.0031449	0.015724	76.59	0.00034594	0.17297	0.50161
A584	0.0010094	0.010391	62.44	0.0044534	0.074224	0.000080162
A585	0.00017345	0.016678	73.33	0.00036692	0.066713	0.482
A586	0.003871	0.019355	99.83	0.00042581	0.2129	0.61742
A587	0.001132	0.1132	92.708	0.00075467	0.1415	0.71694
A588	0.000090909	0.008333	99.176	0.0014	0.19333	1
A589	0.0031449	0.015724	76.59	0.00034594	0.17297	0.50161
A590	0.0010094	0.010391	62.44	0.0044534	0.074224	0.000080162
A591	0.00017345	0.016678	73.33	0.00036692	0.066713	0.482
A592	0.003871	0.019355	99.83	0.00042581	0.2129	0.61742
A593	0.001132	0.1132	92.708	0.00075467	0.1415	0.71694
A594	0.000068182	0.00625	99.176	0.0014	0.145	0.75
A595	0.0011538	0.11538	92.708	0.00076923	0.14423	0.73077
A596	0.0031192	0.015596	76.59	0.00034311	0.17155	0.49751
A597	0.001132	0.1132	92.708	0.00075467	0.1415	0.71694
A598	0.000068182	0.00625	99.176	0.0014	0.145	0.75
A599	0.0011538	0.11538	92.708	0.00076923	0.14423	0.73077
A600	0.0031192	0.015596	76.59	0.00034311	0.17155	0.49751
A601	0.001132	0.1132	92.708	0.00075467	0.1415	0.71694
A602	0.000068182	0.00625	99.176	0.0014	0.145	0.75
A603	0.0011538	0.11538	92.708	0.00076923	0.14423	0.73077
A604	0.0031192	0.015596	76.59	0.00034311	0.17155	0.49751
A605	0.000080995	0.007425	99.176	0.0014	0.17225	0.89095
A606	0.0029859	0.01493	76.59	0.00032845	0.16423	0.47625
A607	0.000080995	0.007425	99.176	0.0014	0.17225	0.89095
A608	0.0029859	0.01493	76.59	0.00032845	0.16423	0.47625
A609	0.000080995	0.007425	99.176	0.0014	0.17225	0.89095
A610	0.0029859	0.01493	76.59	0.00032845	0.16423	0.47625
A611	0.001132	0.1132	92.708	0.00075467	0.1415	0.71694
A612	0.000063174	0.005791	99.176	0.0014	0.13435	0.69491
A613	0.0011538	0.11538	92.708	0.00076923	0.14423	0.73077
A614	0.0029361	0.014681	76.59	0.00032297	0.16149	0.46831

Table D.11 (continued)

	CH4	CO	CO2	N2O	NOX	SO2
A615	0.001132	0.1132	92.708	0.00075467	0.1415	0.71694
A616	0.000063174	0.005791	99.176	0.0014	0.13435	0.69491
A617	0.0011538	0.11538	92.708	0.00076923	0.14423	0.73077
A618	0.0029361	0.014681	76.59	0.00032297	0.16149	0.46831
A619	0.001132	0.1132	92.708	0.00075467	0.1415	0.71694
A620	0.000063174	0.005791	99.176	0.0014	0.13435	0.69491
A621	0.0011538	0.11538	92.708	0.00076923	0.14423	0.73077
A622	0.0029361	0.014681	76.59	0.00032297	0.16149	0.46831
A623	0.001132	0.1132	92.708	0.00075467	0.1415	0.71694
A624	0.000063174	0.005791	99.176	0.0014	0.13434	0.69491
A625	0.0011538	0.11538	92.708	0.00076923	0.14423	0.73077
A626	0.003871	0.019355	99.83	0.00042581	0.2129	0.61742
A627	0.0010094	0.010391	62.44	0.0044534	0.074224	0.000080162
A628	0.00017345	0.016678	73.33	0.00036692	0.066713	0.482
A629	0.0029361	0.014681	76.59	0.00032297	0.16149	0.46831
A630	0.001132	0.1132	92.708	0.00075467	0.1415	0.71694
A631	0.000063174	0.005791	99.176	0.0014	0.13434	0.69491
A632	0.0011538	0.11538	92.708	0.00076923	0.14423	0.73077
A633	0.003871	0.019355	99.83	0.00042581	0.2129	0.61742
A634	0.0010094	0.010391	62.44	0.0044534	0.074224	0.000080162
A635	0.00017345	0.016678	73.33	0.00036692	0.066713	0.482
A636	0.0029361	0.014681	76.59	0.00032297	0.16149	0.46831
A637	0.001132	0.1132	92.708	0.00075467	0.1415	0.71694
A638	0.000063174	0.005791	99.176	0.0014	0.13434	0.69491
A639	0.0011538	0.11538	92.708	0.00076923	0.14423	0.73077
A640	0.003871	0.019355	99.83	0.00042581	0.2129	0.61742
A641	0.0010094	0.010391	62.44	0.0044534	0.074224	0.000080162
A642	0.00017345	0.016678	73.33	0.00036692	0.066713	0.482
A643	0.0029361	0.014681	76.59	0.00032297	0.16149	0.46831
A644	0.0059375	0.016678	73.33	0.00016678	0.060042	0.482
A645	0.0059375	0.016678	73.33	0.00016678	0.060042	0.482
A646	0.0059375	0.016678	73.33	0.00016678	0.060042	0.482
A647	0	0	0	0	0	0
A648	0	0	0	0	0	0
A649	0	0	0	0	0	0

D.6 Other Parameters

The annual capacity expansions for the power plants are restricted based on the observed past investment data [59]. The planning horizon is divided into two and two different limits were added for each time span (second is %20 more than the first). These restrictions are by plant type and are put on the total country investments. They are tabulated in Table D.12.

Table D.12 Maximum Investment in Power Plants

	Maximum Total Investment *(MW)*	
	2003 - 2011	**2012 - 2020**
Hard coal	1500	1800
Lignite	1500	1800
Diesel oil	100	120
Fuel oil	100	120
Natural gas	3000	3600
Wind	50	60
Geothermal	50	60
Small hydroelectric	500	600

The maximum output ratios of each refinery are calculated based on the past data [43]. For each refinery consecutive 7 years' productions (1999 -2005) were assumed to represent these ratios. The productions were converted to energy units. Ratios of each fuel in the total production are found for these years. Maximum of them were used as refinery maximum ratios. Table D.13 presents these parameters.

Table D.13 Refinery Maximum Percentages by Fuel

	Gasoline	Diesel oil	Fuel oil	LPG	Jet Fuel	Other Oil
İzmit	19.20%	30.32%	27.85%	4.07%	9.77%	21.08%
İzmir	18.43%	35.80%	27.90%	3.92%	9.11%	24.51%
Kırıkkale	21.20%	37.44%	27.75%	4.10%	5.99%	19.42%
Batman	6.58%	18.11%	47.17%	0.89%	0.76%	51.11%

Base year composition of sectoral demands is tabulated below [43] in table D.14. The energy sources are on the left. From top to down, the abbreviations correspond to hard coal, lignite, coke, petroleum coke, wood & biomass, LPG, gasoline, jet fuel, diesel oil, fuel oil, other oil, natural gas, electricity geothermal heat and solar heat. The demand sectors are lined above. From left to right the abbreviations correspond to residential sector, transportation sector, industry sector (including iron and steel industry, chemical and petrochemical industry with feedstock, fertilizer industry, cement industry, sugar industry, non-iron metals industry and other industries), agriculture sector and non-energy uses.

Table D.14 Base Year Composition (%)

	RS	**TS**	**IS**							**AS**	**NE**
			ISI	**CPFI**	**FI**	**CI**	**SI**	**NIMI**	**OI**		
HC	3.24			0.00		32.68	5.39	5.35	32.41		
L	6.33			0.32	0.99	17.87	39.87	1.70	8.37		
C	0.69		64.36				6.56	0.94	0.71		
PC						36.32			2.44		
WB	29.36										
LPG	11.19	11.06				0.04			3.13		
GO		25.54									
JF		7.31									
DO		54.66				0.07			2.06	89.83	
FO	2.46	0.81	10.69	25.45	15.92	1.88	36.08	27.44	10.85		
O				46.45							100
NG	18.66			11.24	75.59		12.11	37.24	21.28		
E	22.90	0.62	24.95	16.53	7.50	11.14	0.00	27.33	18.74	10.17	
G	4.00										
S	1.18										

Finally, the investment costs for transmission investment and the capacity of current system is estimated as follows. Regional center of gravities are found for each region by considering the electricity consumption of each city in that region [40]. The capacities of transmission between regions 1-2, and 2-3 are found by summing each transmission line that passes the regional borders. This sum is treated like single transmission lines between the regions. The capacity of this composite line equals to the sum of the capacities of the border passing lines and the characteristics of the lines are the combination of those lines. Table D.15 shows the summary of transmission line types, lengths and costs [67] which constitute the composite lines between regionsand the associated interregional transmission capcities and unit investment costs.

Table D.15 Transmission Between Regions

Type	Regions 1-2			Regions 2-3		
	Number of lines	**Average length** *(km)*	**Cost** *(M $)*	**Number of lines**	**Average length** *(km)*	**Cost** *(M $)*
1 * 477	7	55.8	14.3	3	75.9	8.7
1 * 795	0	0	0	1	21	1.2
2 * 795	2	85.6	15.2	4	67.3	25.0
2R	3	202.7	55.3	2	271	51.5
2C	2	128.5	23.4	2	108.5	20.6
3C	1	206	25.3	4	305	155.6
3Ph	2	308.5	88.8	3	282	126.0
Total cost	222.3 M $			388.6 M $		
Average cost	19,430 $/MVA			22,146 $/MVA		
Capacity	11,443 MVA			17,549 MVA		

Appendix E: GAMS Code

The GAMS code is written in Courier New font type for better readability.

```
********************************
***** Turkish Energy Model *****
********* Developed by *********
******* Tolga Han Seyhan *******
********************************


SETS

I "Nodes"    / N001*N251 /

* Set I defines the nodes, in other words, the fuels located in
the network.

  Demand(I) "All demand nodes without sector differentiation"
  / N095*N127 /

  Intermediate(I) "All intermediate nodes"
  / N004, N005, N006, N009, N010, N014*N019,N022,
    N023, N026*N048,  N053, N054, N072*N094, N128*N250 /

  Supply(I) "All supply nodes in the network"
  / N001, N002, N003, N007, N008, N011, N012, N013, N020, N021,
    N024, N025, N049, N050, N051, N052, N055, N056, N057, N058,
    N059, N060, N061, N062, N063, N064, N065, N066, N067, N068,
    N069, N070, N071, N251 /

  Trans(I) "All demand nodes for transportation sector"
  / N098*N100 /

  ElecN(I)  "Nodes for electricity generation and transmission"
  / N058*N062, N063*N066, N067*N071, N072*N094, N251 /

  ElecIN(I) "Intermediate nodes for electricity network"
  / N087*N091 /

  ElecRN(I) "Resource nodes for electricity network"
  / N058*N062, N063*N066, N067*N071, N072*N086, N251 /

  ElecDN(I) "Peak demand node in the electricity network"
  / N092, N093, N094 /


J "Arcs"     / A001*A650 /

* Set J defines the arcs, in other words, conversion and
transportation activities in the network.

  Consumption(J) "End use of fuel"
```

```
  / A153*A155, A169*A171, A185*A190, A206, A222, A238, A244, A250,
    A256, A268, A269, A281, A282, A294, A295, A311, A327, A343,
    A362, A363, A374, A375, A382, A383, A390, A391, A398, A399,
    A410, A411, A422, A423, A434, A435, A453, A454, A472, A473,
    A491, A492, A496, A500, A504, A514*A516, A525*A649 /

  ElecConsum(J) "Consumption of electricity in sectors"
  / A188, A189, A190, A206, A222, A238, A244, A250, A256, A269,
    A282, A295, A311, A327, A343, A363, A375, A383, A391, A399,
    A411, A423, A435, A454, A473, A492, A496, A500, A504, A526 /

  TransDiesel(J)  "Diesel in transportation"
  / A543, A548, A553 /

  TransGasoline(J)  "Gasoline in transportation"
  / A542, A547, A552 /

  TransLPG(J)  "Gasoline in transportation"
  / A545, A550, A555 /

  TransJetFuel(J)  "Jet Fuel in transportation"
  / A546, A551, A556 /

* These are the arcs that denote refining activities
  REF1(J)  "Output arcs of Izmit refinery"          / A035*A040 /
  REF2(J)  "Output arcs of Izmir refinery"          / A041*A046 /
  REF3(J)  "Output arcs of Kirikkale refinery"      / A047*A052 /
  REF4(J)  "Output arcs of Batman refinery"         / A053*A058 /

* These are the arcs for electricity generation and transmission

  ElecA(J)  "All generation and transmission arcs"
  / A102*A139, A650 /

  ElecAG(J) "Arcs representing the power plant activities"
  / A102*A110, A112*A120, A121*A129, A650 /

  ElecHC(J)  "Hard coal fired power plants"   / A102, A112, A121 /

  ElecL(J)   "Lignite fired power plants"     / A103, A113, A122 /

  ElecD(J)   "Diesel oil fired power plants"  / A104, A114, A123 /

  ElecFO(J)  "Fuel oil fired power plants"    / A105, A115, A124 /

  ElecNG(J)  "Natural gas fired power plants" / A106, A116, A125 /

  ElecW(J)   "Wind power plants"              / A107, A117, A126 /

  ElecG(J)   "Geothermal power plants"        / A108, A118, A127 /

  ElecH1(J)  "Hydroelectric power plants"     / A109, A119, A128 /

  ElecH2(J)  "Hydroelectric power plants"     / A110, A120, A129 /
```

```
* These arcs (resource production) have capacity and reserve
limits (ie. extraction, mining)

  Capacitated(J) "All resources that have capacities"
  / A003, A015, A016, A017, A026, A095, A098, A154, A155, A170,
    A171, A186, A187, A514, A515, A516 /

  Geothermal(J)  "Geothermal resources"  / A154, A170, A186 /

  Solar(J)       "Solar resources"       / A155, A171, A187 /

  Imports(J)     "Imported resources"
  / A001, A002, A006, A007, A024, A025, A031*A034,
    A059*A076, A096, A097, A111, A130, A650 /

  Domestics(J)   "Domestic resources"
  / A003, A015*A017, A026, A095, A514*A516, A154, A155,
    A170, A171, A186, A187, A107*A110, A117*A120, A126*A129 /

T "Planning period"             / 2003*2020 /

EM "Substances whose emissions are calculated"
 / CH4, CO, CO2, N2O, NOX, SO2 /

H "Hydroelectric power plants with capacity > 200 MW"
 / HA01*HA20 /

alias (J,JJ);
alias (T,TT);

SCALARS

* These scalars convert the former unit to the latter
KCALtoTOE    / 0.0000001 /
MWHtoTOE     / 0.0859781 /
KWHtoTOE     / 0.0000859781 /
GJtoTOE      / 0.023883 /

* These scalars represent the processing (not production)
capacitites of each refinery in Turkey.

R1_CAPINP    / 10000000  /
R2_CAPINP    / 10000000  /
R3_CAPINP    /  5000000  /
R4_CAPINP    /  1100000  /

* Investment cost per ton per year for refineries
R_CAPC       / 200 /

* Investment cost for the nuclear plant in Akkuyu or Sinop
NUCLEARCOST  / 2625000000 /

* Transmission capacity in MW between regions. See
"...\Bolgeli\Iletim_Kapasite.xls" for calculations
TRANS_1_2 / 11443 /
TRANS_2_3 / 17549 /
```

```
* Cost of increasing the transmission capacity between regions by
1 MW See "...\Bolgeli\Iletim_Kapasite.xls" for calculations
CTRANS_1_2 / 19430 /
CTRANS_2_3 / 22146 /

* Discount rate used in finding the present worth of the payments
DRATE / 0.1 /


TABLE
IN(J,I) "Transpose of the node-arc incidence matrix due to excel
limitations"

$include "C:\Documents and Settings\Travis
Bickle\Belgelerim\Thesis\Nukleer Bolgeli\inp_incidence.INC"
;
* This matrix shows the entering and leaving arcs for each node
* or similarly the origin and destination pair for each arc.
* It will be used to form the matrix M with efficiencies of arcs
* 1 denotes that the arc J enters node I,
* -1 denotes that the arc J leaves node I
* " " means that the node and arc has no connection

*******************************************************************

TABLE
D(I,T) "Demands for each demand node in a given year T"

$include "C:\Documents and Settings\Travis
Bickle\Belgelerim\Thesis\Nukleer Bolgeli\inp_demand.INC" ;

*******************************************************************

TABLE
DE(I,T) "Demands of electricity for each demand node in a given
year T"

$include "C:\Documents and Settings\Travis
Bickle\Belgelerim\Thesis\Nukleer
Bolgeli\inp_demandelectricity.INC" ;

*******************************************************************

*TABLE
*S(I,T) "Supplies for each supply node in a given year T"
*
*$include "C:\Documents and Settings\Travis
Bickle\Belgelerim\Thesis\Bolgeli\input_supplies.INC"
*;

*******************************************************************

TABLE
EMIT(J,EM) "Emission factors of each activity defined"
```

```
$include "C:\Documents and Settings\Travis
Bickle\Belgelerim\Thesis\Nukleer Bolgeli\inp_emissionfactors.INC"
;
TABLE
CINP(J,T) "Conversion-transportation cost per unit on arc J"

$include "C:\Documents and Settings\Travis
Bickle\Belgelerim\Thesis\Nukleer Bolgeli\inp_conversioncosts.INC"
;

*****************************************************************

PARAMETERS

E(J) "Thermal eficiency of operation J"
/
$include "C:\Documents and Settings\Travis
Bickle\Belgelerim\Thesis\Nukleer Bolgeli\inp_efficiency.INC"
/

*****************************************************************

ARCCAPINP(J) "Input capacities for capacitated arcs that will then
be turned into common energy units"
/
$include "C:\Documents and Settings\Travis
Bickle\Belgelerim\Thesis\Nukleer Bolgeli\inp_arccapacities.INC"
/

*****************************************************************

ARCCAPCINP(J) "Capacity expansion cost given in the units in
ARCCAPTYP(J) parameter (ie. original units)"
/
$include "C:\Documents and Settings\Travis
Bickle\Belgelerim\Thesis\Nukleer Bolgeli\inp_arccapacitycosts.INC"
/

*****************************************************************

ARCRESINP(J) "Reserves for fuel resources"
/
$include "C:\Documents and Settings\Travis
Bickle\Belgelerim\Thesis\Nukleer Bolgeli\inp_arcreserves.INC"
/

RENEWRESINP(J)  "Maximum available capacities for renewable
resources"
/
$include "C:\Documents and Settings\Travis
Bickle\Belgelerim\Thesis\Nukleer Bolgeli\inp_hydrogeosolarmax.INC"
/

*****************************************************************
```

```
ARCCAPTYP(J) "The unit of capacity in arc J: ton, m3, barrel and
MW"
/
$include "C:\Documents and Settings\Travis
Bickle\Belgelerim\Thesis\Nukleer Bolgeli\inp_arccapacitytypes.INC"
/
*****************************************************************

POWCAPINP(J) "Installed power generation capacity"
/
$include "C:\Documents and Settings\Travis
Bickle\Belgelerim\Thesis\Nukleer Bolgeli\inp_powercapacities.INC"
/

*****************************************************************

POWCAPCINP(J) "Investment cost per MW for power generation"
/
$include "C:\Documents and Settings\Travis
Bickle\Belgelerim\Thesis\Nukleer
Bolgeli\inp_powercapacitycosts.INC"
/

*****************************************************************

POWFIXC(J)
/
$include "C:\Documents and Settings\Travis
Bickle\Belgelerim\Thesis\Nukleer Bolgeli\inp_powerfixedcosts.INC"
/

*****************************************************************

POWVARC(J)
/
$include "C:\Documents and Settings\Travis
Bickle\Belgelerim\Thesis\Nukleer
Bolgeli\inp_powervariablecosts.INC"
/

*****************************************************************

POWMODEL(J) "Model type for power plant investments"
/
$include "C:\Documents and Settings\Travis
Bickle\Belgelerim\Thesis\Nukleer Bolgeli\inp_powermodeltypes.INC"
/

*****************************************************************

ARCUNIT(J) "The unit of capacity in arc J: ton, m3, MWt barrel and
kWh"
/
$include "C:\Documents and Settings\Travis
Bickle\Belgelerim\Thesis\Nukleer Bolgeli\inp_arcmeasureunits.INC"
/
```

```
****************************************************************

UNITCAL(J) "Unit calorific value of the fuel in Kcal/kg or
Kcal/m3"
/
$include "C:\Documents and Settings\Travis
Bickle\Belgelerim\Thesis\Nukleer
Bolgeli\inp_unitcalorificvalue.INC"
/

****************************************************************

PFAC(J) "Plant factors that relate planned working hours to
available operational hours"
/
$include "C:\Documents and Settings\Travis
Bickle\Belgelerim\Thesis\Nukleer Bolgeli\inp_plantfactors.INC"
/

****************************************************************

BASECOMP(J) "Base year composition of demand in a given region"
/
$include "C:\Documents and Settings\Travis
Bickle\Belgelerim\Thesis\Nukleer Bolgeli\inp_basecomp.INC"
/

****************************************************************

REFMAX(J) "Maximum output percents of the refineries in TOE's"
/
$include "C:\Documents and Settings\Travis
Bickle\Belgelerim\Thesis\Nukleer Bolgeli\input_refinery_max.INC"
/

****************************************************************

PEAK(T) "Peak load prediction for 2003-2020"
/
2003        21729
2004        23199
2005        25000
2006        28270
2007        30560
2008        33075
2009        35815
2010        38785
2011        41965
2012        45410
2013        49030
2014        52905
2015        57050
2016        60845
2017        65245
2018        69835
```

```
2019        74585
2020        79350
/
******************************************************************

PEAK_COMP(I) "The regional composition of the peak load in
percentage. Obtained from TEIAS"
/
N092      0.6276
N093      0.1931
N094      0.1793
/

******************************************************************

HYDROARC(H) "The region that the project belongs to"
/
$include "C:\Documents and Settings\Travis
Bickle\Belgelerim\Thesis\Nukleer Bolgeli\inp_hydroarcs.INC"
/

******************************************************************

HYDROCAP(H) "Capacities of hydroelectric power plant projects in
MW"
/
$include "C:\Documents and Settings\Travis
Bickle\Belgelerim\Thesis\Nukleer Bolgeli\inp_hydrocapacity.INC"
/

******************************************************************

HYDROCOST(H) "Cost of hydroelectric power plant projects in $"
/
$include "C:\Documents and Settings\Travis
Bickle\Belgelerim\Thesis\Nukleer Bolgeli\inp_hydrocost.INC"
/

******************************************************************

HYDROFACTOR(H) "Plant factors of hydroelectric power plant
projects"
/
$include "C:\Documents and Settings\Travis
Bickle\Belgelerim\Thesis\Nukleer Bolgeli\inp_hydroplantfactor.INC"
/


* Parameters to be calculated from the existing ones
M(I,J)          "The matrix with efficiency entries, it's made
from matrix IN"
MELEC(I,J)      "The matrix showing the electricity network node-
arc incidence structure"
ARCCAP(J)       "Capacity of each capacitated arc in common units
(toe)"
```

```
ARCCAPC(J)      "Investment cost for each capacitated arc in $ /
toe"
POWCAP(J)
POWCAPC(J)
C(J,T)          "Unit cost of performing activity J in $ / common
units (TOE)"

*CAP(J)          "Capacity of activity J in common units (TOE)"
*CAPC(J)         "Capacity expansion cost of activity J in $ /
common units (TOE)"
TRANS_1_2_CAP   "The electricity transmission capacity between
regions 1 and 2"
TRANS_2_3_CAP   "The electricity transmission capacity between
regions 2 and 3"
CAPCTRANS_1_2   "The capacity expansion cost of the transmission
between regions 1 and 2 per common unit"
CAPCTRANS_2_3   "The capacity expansion cost of the transmission
between regions 2 and 3 per common unit"
PVI(T)          "PV to A with useful life (=30) then A to PV with
remaining planning periods at year T"
PV(T)           "PV of a given payment at year T"
;

* The following loop calculates the entries of the M matrix, given
the initial incidence matrix. It replaces 1's with E(J)'s and
transposes IN(I,J)
 Loop (I,
 Loop (J,
       if (  IN(J,I) = 1,
             M(I,J) = E(J);
       else
             M(I,J) = IN(J,I);
          )
       )
       )
;

* The following equation creates the arc incidence matrix for the
electricity generation and transmission network from the transpose
of IN(J,I)

  MELEC(I,J)$(ElecN(I) AND ElecA(J)) = IN(J,I) ;

* The following loop converts the capacity of each capacitated arc
to TOE
* Capacity type 1 -> ton / year (x 1000 to convert kcal/kg to
kcal/ton)
* Capacity type 2 -> m3 / year
* Capacity type 3 -> MWt / year (0.45 load factor is used)
* Capacity type 4 -> toe / year

 Loop (J,
       if (   ( ARCCAPTYP(J) = 1 ),
                ARCCAP(J) = ARCCAPINP(J)* UNITCAL(J) * 1000 *
KCALtoTOE;
```

```
                 ARCCAPC(J) = ARCCAPINP(J) / ( UNITCAL(J) * 1000 *
KCALtoTOE );

       elseif ( ARCCAPTYP(J) = 2 ),
                 ARCCAP(J) = ARCCAPINP(J)* UNITCAL(J) * KCALtoTOE;
                 ARCCAPC(J) = ARCCAPINP(J) / ( UNITCAL(J) *
KCALtoTOE );

       elseif ( ARCCAPTYP(J) = 3 ),
                 ARCCAP(J) = ARCCAPINP(J) * 0.45 * 8760 *
MWHtoTOE;
                 ARCCAPC(J) = ARCCAPCINP(J) / ( 0.45 * 8760 *
MWHtoTOE );

       elseif ( ARCCAPTYP(J) = 4 ),
                 ARCCAP(J) = ARCCAPINP(J);
                 ARCCAPC(J) = ARCCAPCINP(J);

           )
      );

* The following loop converts the capacity (MW) and the investment
cost ($/MW) of each power plant to the common units (toe and
$/TOE)

 Loop (J,
        if ( (PFAC(J) > 0),
                 POWCAP(J) = POWCAPINP(J) * PFAC(J) * 8760 *
MWHtoTOE;
                 POWCAPC(J) = POWCAPCINP(J) / ( PFAC(J) * 8760 *
MWHtoTOE );
           )
      );



* The following loop converts the activity cost expressed in
original units
* to the common units ($/toe)
* Arcunit: 1 -> tons
* Arcunit: 2 -> m3
* Arcunit: 3 -> kwh
* Arcunit: 4 -> mwt (load factor = 0.45)
* Arcunit: 5 -> toe

 Loop (J,
 Loop (T,
       if (   ( ARCUNIT(J) = 1 ),
                 C(J,T) = CINP(J,T) / ( UNITCAL(J) * 1000 *
KCALtoTOE );

       elseif ( ARCUNIT(J) = 2 ),
                 C(J,T) = CINP(J,T) / ( UNITCAL(J) * KCALtoTOE );

       elseif ( ARCUNIT(J) = 3 ),
                 C(J,T) = CINP(J,T) / ( KWHtoTOE );
```

```
       elseif ( ARCUNIT(J) = 4 ),
                 C(J,T) = CINP(J,T) / ( 0.45 * 8760 * 1000 *
KWHtoTOE );

       elseif ( ARCUNIT(J) = 5 ),
                 C(J,T) = CINP(J,T);

           )
       )
       )
;

* Assuming the lines transmit electricity at all available working
hours

TRANS_1_2_CAP = TRANS_1_2 * 365 * 24 * MWHtoTOE;
TRANS_2_3_CAP = TRANS_2_3 * 365 * 24 * MWHtoTOE;


CAPCTRANS_1_2 = CTRANS_1_2 / (365 * 24 * MWHtoTOE);
CAPCTRANS_2_3 = CTRANS_2_3 / (365 * 24 * MWHtoTOE);


PVI(T)= (DRATE * (1 + DRATE)**30)/((1 + DRATE)**30-1)*((1 +
DRATE)**(CARD(T)-ORD(T))-1)/(DRATE*(1+DRATE)**(CARD(T)-ORD(T)));
PV(T)   = (1 + DRATE)**(-(ORD(T)-1));


*****************************************************************
*****************************************************************
*************************** VARIABLES ***************************
*****************************************************************
*****************************************************************


VARIABLE
COST   "Total cost"


BINARY VARIABLES
OPENPLANT(J,T)
OPENHYDRO(H,T)
OPENNUCLEAR(T)


POSITIVE VARIABLES
X(J,T)   "Flow through arc J in year T"

EMISSION(EM,T)     "Total emission of a given substance (EM) by
year"

REFINV1(T)     "Refinery capacity expansion in year T"
REFINV2(T)     "Refinery capacity expansion in year T"
REFINV3(T)     "Refinery capacity expansion in year T"
REFINV4(T)     "Refinery capacity expansion in year T"
```

```
R1_CAP(T) "Refinery capacity at T"
R2_CAP(T) "Refinery capacity at T"
R3_CAP(T) "Refinery capacity at T"
R4_CAP(T) "Refinery capacity at T"

PIPEINV1(T) "Pipeline capacity expansion for domestic oil
transport to Refineries 1, 2, 3"
PIPEINV2(T) "Pipeline capacity expansion for oil transport to
Refinery 3"

TRANSINV12(T) "Transmission line capacity expansion between
Regions 1 and 2"
TRANSINV23(T) "Transmission line capacity expansion between
Regions 2 and 3"

POWINV(J,T)   "Capacity expansion for power generation"

CAPINV(J,T)   "Capacity expansion for activities other than above
ones"

P(J,T)   "Peak load satisfaction variable in MW"

K(I,J,T)  "Percentage of demand increase in I from T-1 to T,
satisfied by J"


*Accounting variables
GENCAP(J,T)  "Generation capacity of plant J"
COSTACT(T)  "Cost of activities in year T"
COSTINV(T)  "Cost of investments in year T"



*****************************************************************
*****************************************************************
********************* EQUATION DECLARATIONS ********************
*****************************************************************
*****************************************************************


EQUATIONS

OBJECTIVE    "Cost of transportation purchasing etc"
BALANCE_D    "Balance at each demand node - flow conservation"
BALANCE_I    "Balance at each intermediate node - flow
conservation"

ELECDEMAND    "Electricity demand at each demand node"

BASEYEAR    "Consumption ratios in the base year"

REF1_CAP    "Output capacity of Izmit refinery"
REF2_CAP    "Output capacity of Izmir refinery"
REF3_CAP    "Output capacity of Kirikkale refinery"
```

```
REF4_CAP    "Output capacity of Batman refinery"

REF1_CAPINV    "Capacity investment in Region 1"
REF2_CAPINV    "Capacity investment in Region 1"
REF3_CAPINV    "Capacity investment in Region 2"
REF4_CAPINV    "Capacity investment in Region 3"

REF1_MAXINV    "Refinery 1 maximum investment"
REF2_MAXINV    "Refinery 2 maximum investment"
REF3_MAXINV    "Refinery 3 maximum investment"
REF4_MAXINV    "Refinery 4 maximum investment"

REF1_MAX    "Maximum output constraints for Izmit refinery"
REF2_MAX    "Maximum output constraints for Izmir refinery"
REF3_MAX    "Maximum output constraints for Kirikkale refinery"
REF4_MAX    "Maximum output constraints for Batman refinery"

EMISSIONS    "Total emission of a substance in year T"
*KYOTO      "Limit on CO2 emissions"

OIL_REF123_CAP    "Capacity of pipeline transportation for
domestic oil to refineries 1,2,3"

OIL_REF3_CAP    "Capacity of pipeline transportation for all oil
to Kirikkale refinery"

ARCCAPACITY    "Capacity constraint of each arc"
MAXCAPEXP      "maximum capacity increase in capacitated arcs"
RESERVES       "Reserves for depletable natural resources"

GEOMAX         "Annual reserve for geothermal energy investment"
SOLARMAX       "Annual reserve for solar energy investment"
HYDROMAX1      "Reserves for hydroelectricity in region 1"
HYDROMAX2      "Reserves for hydroelectricity in region 2"
HYDROMAX3      "Reserves for hydroelectricity in region 3"

LINPOWER    "Capacity constraint for power plants modeled as
linear"

FVPOWER1    "Capacity constraint for power plants modeled as
linear with fixed costs"
FVPOWER2    "Constraint guaranteeing fixed cost to be incurred"

PROJECTHYDRO    "Capacity constraint for hydroelectric power plant
projects"
HYDROUNIQUE     "Constraint guaranteeing a plant to be opened at
most once"

PROJECTNUCLEAR    "Capacity constraint for nuclear power plant
project"
NUCLEARUNIQUE     "Constraint guaranteeing the plant to be opened
at most once"

BAL_PEAK_D     "The balance equation to satisfy the peak load - if
demand node"
```

```
BAL_PEAK_I     "The balance equation to satisfy the peak load - if
intermediate node"
BAL_PEAK_S     "The balance equation to satisfy the peak load - if
supply"


PEAKTRANSMISSION12    "Transmission capacity in MW to satisfy peak
load Region 1 <-> Region 2"
PEAKTRANSMISSION23    "Transmission capacity in MW to satisfy peak
load Region 2 <-> Region 3"

STOCK1   "Stock flow structure of deman satisfaction"
STOCK2   "Demand increase satisfaction"

TRANS_D1   "Diesel in transportation sector region 1"
TRANS_D2   "Diesel in transportation sector region 2"
TRANS_D3   "Diesel in transportation sector region 3"

TRANS_J1   "Jet Fuel in transportation sector region 1"
TRANS_J2   "Jet Fuel in transportation sector region 2"
TRANS_J3   "Jet Fuel in transportation sector region 3"

TRANS_G1   "Gasoline and LPG in transportation sector region 1"
TRANS_G2   "Gasoline and LPG in transportation sector region 2"
TRANS_G3   "Gasoline and LPG in transportation sector region 3"

FEEDST_1  "Feedstock part of the fuwl used"
FEEDST_2  "Feedstock part of the fuwl used"
FEEDST_3  "Feedstock part of the fuel used"

GENCAPACITY  "Generation capacity of a plant type at year T"

MAXGENCAP_HC   "Capacity increase limit for a hard coal plant in
year T"
MAXGENCAP_L    "Capacity increase limit for a lignite plant in
year T"
MAXGENCAP_D    "Capacity increase limit for a diesel oil plant in
year T"
MAXGENCAP_FO   "Capacity increase limit for a fuel oil plant in
year T"
MAXGENCAP_NG   "Capacity increase limit for a natural gas plant in
year T"
MAXGENCAP_W    "Capacity increase limit for a wind plant in year
T"
MAXGENCAP_G    "Capacity increase limit for a geothermal plant in
year T"
MAXGENCAP_H1   "Capacity increase limit for a hydroelectric plant
in year T"
MAXGENCAP_H2   "Capacity increase limit for a hydroelectric plant
in year T"


HYDROTIMING    "Minimum realization date for hydro projects"
NUCLEARTIMING  "Minimum realization date for nuclear project"

COST1   "Cost of activities in year T"
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COST2   "Cost of investments in year T"


*NATIONAL  "At least 50% of all resources used will be domestic
after 2015"
;


*****************************************************************
*****************************************************************
****************** OBJECTIVE AND CONSTRAINTS ******************
*****************************************************************
*****************************************************************


* Minimize the sum of all activities discounted to 2003 by
satisfying all the demand

OBJECTIVE..    COST =E= SUM(T, PV(T) * SUM(J, C(J,T) * E(J) *
X(J,T)))
                        + SUM(T, PVI(T) * PV(T) * (SUM(J,
ARCCAPC(J) * CAPINV(J,T))
                             + SUM(J, POWCAPC(J) * POWINV(J,T))
                             + SUM(J, POWVARC(J) * POWINV(J,T) +
POWFIXC(J) * OPENPLANT(J,T))
                             + SUM(H, HYDROCOST(H) *
OPENHYDRO(H,T))
                             + NUCLEARCOST * OPENNUCLEAR(T)
                             + R_CAPC * (REFINV1(T) + REFINV2(T) +
REFINV3(T) + REFINV4(T))
                             + CTRANS_1_2 * TRANSINV12(T) +
CTRANS_2_3 * TRANSINV23(T)));



* The net flow out from a node should be one of them:
* a) greater than the demand (if the node is a demand node)
* b) less than the supply (if the node is a supply node)
* c) zero (if the node is an intermediate node)

BALANCE_D(I,T)$(Demand(I))..            SUM(J, M(I,J) * X(J,T))
=G= D(I,T) ;

BALANCE_I(I,T)$(Intermediate(I))..      SUM(J, M(I,J) * X(J,T))
=E= 0      ;

* Electricity demand at each demand node
ELECDEMAND(I,J,T)$(ElecConsum(J) and IN(J,I) = 1 and ord(T) > 1)..

E(J) * X(J,T) =G= DE(I,T);

* In year 2003 the consumption in terms of consumed fuels and
their percentages is realized as: (Amount satisfied by fuel J) >=
(Base year contribution of J) * (Demand for node I where I is the
sink node for J)
```

```
BASEYEAR(I,J,'2003')$(Consumption(J) and IN(J,I) = 1).. E(J) *
X(J,'2003') =G= BASECOMP(J) * D(I,'2003');


* The total amount of the processed oil in a refinery is limited
by the capacity of that refinery. Note that as Efficiency is not
used here
* X(J,T) represents the oil processed not the output

REF1_CAP(T)..   SUM(J$(REF1(J)), X(J,T)) =L= R1_CAP(T) ;
REF2_CAP(T)..   SUM(J$(REF2(J)), X(J,T)) =L= R2_CAP(T) ;
REF3_CAP(T)..   SUM(J$(REF3(J)), X(J,T)) =L= R3_CAP(T) ;
REF4_CAP(T)..   SUM(J$(REF4(J)), X(J,T)) =L= R4_CAP(T) ;


* Capacity investment in refinery construction

REF1_CAPINV(T).. R1_CAP(T) =E= R1_CAPINP + SUM(TT$(ORD(TT) lt
ORD(T)),REFINV1(TT));

REF2_CAPINV(T).. R2_CAP(T) =E= R2_CAPINP + SUM(TT$(ORD(TT) lt
ORD(T)),REFINV2(TT));

REF3_CAPINV(T).. R3_CAP(T) =E= R3_CAPINP + SUM(TT$(ORD(TT) lt
ORD(T)),REFINV3(TT));

REF4_CAPINV(T).. R4_CAP(T) =E= R4_CAPINP + SUM(TT$(ORD(TT) lt
ORD(T)),REFINV4(TT));

* Maximum capacity expansion for refineries

REF1_MAXINV(T)$(ORD(T) > 1)..  R1_CAP(T) =L= 1.2 * R1_CAP(T-1) ;
REF2_MAXINV(T)$(ORD(T) > 1)..  R2_CAP(T) =L= 1.2 * R2_CAP(T-1) ;
REF3_MAXINV(T)$(ORD(T) > 1)..  R3_CAP(T) =L= 1.2 * R3_CAP(T-1) ;
REF4_MAXINV(T)$(ORD(T) > 1)..  R4_CAP(T) =L= 1.2 * R4_CAP(T-1) ;



* Each item in a refinery's product spectrum can at most
constitute a predetermined percent of the total output. This
maximum is found by analysing the data of the last 7 years and
accepting it as the refinery characteristic

REF1_MAX(J,T)$(REF1(J))..   E(J)*X(J,T) =L= REFMAX(J) *
SUM(JJ$(REF1(JJ)), E(JJ) * X(JJ,T));

REF2_MAX(J,T)$(REF2(J))..   E(J)*X(J,T) =L= REFMAX(J) *
SUM(JJ$(REF2(JJ)), E(JJ) * X(JJ,T));

REF3_MAX(J,T)$(REF3(J))..   E(J)*X(J,T) =L= REFMAX(J) *
SUM(JJ$(REF3(JJ)), E(JJ) * X(JJ,T));

REF4_MAX(J,T)$(REF4(J))..   E(J)*X(J,T) =L= REFMAX(J) *
SUM(JJ$(REF4(JJ)), E(JJ) * X(JJ,T));
```

```
* Emission of a substance in a given year is the sum of all
activities' individual emission values that year. Limits the
emission of CO2 to a ceratin percent of 1990 emissions

*KYOTO(T)$(ord(T) > 17).. EMISSION('CO2',T) =L= 223806000000;
EMISSIONS(EM,T)..   EMISSION(EM,T) =E= SUM(J, EMIT(J,EM) * X(J,T))
/ GJtoTOE;

*139594000000
*223806000000
*230987000000


* The transportation of domestic crude oil from Batman to
refineries 1,2 and 3 is limited by the capacity of the batman-
ceyhan pipeline.

OIL_REF123_CAP(T)..  X('A027',T) + X('A028',T) + X('A029',T) =L=
3500000 ;


* The amount of oil transported to Kirikkale refinery is limited
by the capacity of the ceyhan-kirikkale pipeline

OIL_REF3_CAP(T)..    X('A029',T) + X('A033',T) =L= 5000000 ;


* The flow through arc J is limited by the capacity of that arc

ARCCAPACITY(J,T)$(Capacitated(J)).. E(J) * X(J,T) =L= ARCCAP(J) +
SUM(TT$(ORD(TT) lt ORD(T)),CAPINV(J,TT));


* Each year capacity expansion is limited to the 20% of the
exisiting capacity

MAXCAPEXP(J,T)$(Capacitated(J) and ORD(T) > 1)..  ARCCAP(J) +
SUM(TT$(ORD(TT) lt ORD(T)), CAPINV(J,TT)) =L= 1.2 *(ARCCAP(J)+
SUM(TT$(ORD(TT) lt ORD(T)-1),CAPINV(J,TT)));


* Reserves of natural resources
RESERVES(J,T)$(ARCRESINP(J) > 0).. (SUM(TT$(ORD(TT) lt ORD(T)+1),
E(J) * X(J,TT)) / (UNITCAL(J) * 1000 * KCALTOTOE))$(ARCCAPTYP(J) =
1)
                                   + (SUM(TT$(ORD(TT) lt ORD(T)+1),
E(J) * X(J,TT)) / (UNITCAL(J) * KCALTOTOE))$(ARCCAPTYP(J) = 2) =L=
ARCRESINP(J);


* Maximum capacity addition to geothermal, solar

GEOMAX(J,T)$(Geothermal(J))..  CAPINV(J,T) / ( 0.45 * 8760 * 1000
* KWHtoTOE ) =L= (300)$(ord(T) < 9) + (260)$(ord(T) >= 9);
SOLARMAX(J,T)$(Solar(J))..  CAPINV(J,T) =L= 30000;
```

```
* Hydroelectricty capacity of Turkey

HYDROMAX1(T)..  (SUM(TT$(ORD(TT) lt ORD(T)), E('A110') *
X('A110',TT)) / (PFAC('A110') * 8760 * MWHtoTOE)) =L= 0.8 *
RENEWRESINP('A110');

HYDROMAX2(T)..  (SUM(TT$(ORD(TT) lt ORD(T)), E('A120') *
X('A120',TT)) / (PFAC('A120') * 8760 * MWHtoTOE)) =L= 0.8 *
RENEWRESINP('A120');

HYDROMAX3(T)..  (SUM(TT$(ORD(TT) lt ORD(T)), E('A129') *
X('A129',TT)) / (PFAC('A129') * 8760 * MWHtoTOE)) =L= 0.8 *
RENEWRESINP('A129');
* Power plant capacity constraints defined for each model type
separately

LINPOWER(J,T)$(POWMODEL(J) = 1)..  E(J) * X(J,T) =L= POWCAP(J) +
SUM(TT$(ORD(TT) lt ORD(T)),POWINV(J,TT));

FVPOWER1(J,T)$(POWMODEL(J) = 2)..  E(J) * X(J,T) =L= POWCAP(J) +
SUM(TT$(ORD(TT) lt ORD(T)),POWINV(J,TT));

FVPOWER2(J,T)$(POWMODEL(J) = 2)..  POWINV(J,T) =L= 1000000000 *
OPENPLANT(J,T);

PROJECTHYDRO(J,T)$(POWMODEL(J) = 3)..  E(J) * X(J,T) =L= POWCAP(J)
+ SUM(TT$(ORD(TT) lt ORD(T)), SUM(H$(HYDROARC(H) = ord(J)),
HYDROCAP(H) * HYDROFACTOR(H) * 8760 * OPENHYDRO(H,TT) *
MWHtoTOE));

HYDROUNIQUE(H)..  SUM(T, OPENHYDRO(H,T)) =L= 1;

PROJECTNUCLEAR(J,T)$(POWMODEL(J) = 4)..  E(J) * X(J,T) =L=
POWCAP(J) + SUM(TT$(ORD(TT) lt ORD(T)), OPENNUCLEAR(TT) * 0.9 *
8760 * 1500 * MWHtoTOE);

NUCLEARUNIQUE.. SUM(T, OPENNUCLEAR(T)) =L= 1;


* Similar to the previous balance equation but creates the flow in
the electricity generation and transmission network, by satisfying
the supply and demand constraints

BAL_PEAK_D(I,T)$(ElecDN(I))..  SUM(J$(ElecA(J)),
MELEC(I,J)*P(J,T)) =G= 1.15 * (PEAK_COMP(I)*PEAK(T))$(ElecDN(I));

BAL_PEAK_I(I,T)$(ElecIN(I))..  SUM(J$(ElecA(J)),
MELEC(I,J)*P(J,T)) =E= 0;

BAL_PEAK_S(I,T)$(ElecRN(I))..  SUM(J$(ElecA(J)),
MELEC(I,J)*P(J,T)) =G= - SUM(J$(ElecA(J) and MELEC(I,J) = -1),
GENCAP(J,T));


* The amount of power supplied between regions is at most equal to
the transmission capacity between regions.
```

```
PEAKTRANSMISSION12(T)..         P('A133',T) + P('A135',T) =L=
TRANS_1_2 + SUM(TT$(ORD(TT) lt ORD(T)),TRANSINV12(TT));

PEAKTRANSMISSION23(T)..         P('A136',T) + P('A137',T) =L=
TRANS_2_3 + SUM(TT$(ORD(TT) lt ORD(T)),TRANSINV23(TT));


* Stock and flow structure of sectoral demands.
* Previous years' decisions are like capital stock, the decision
is made on the  demand increase

STOCK1(I,J,T)$(Consumption(J) and IN(J,I) = 1 and ord(T) > 1)..
E(J) * X(J,T) =G= E(J) * X(J,T-1) + K(I,J,T) * ( D(I,T)-D(I,T-1));

STOCK2(I,T)$(Demand(I) and ord(T) > 1)..  SUM(J$(IN(J,I) = 1),
K(I,J,T)) =E= 1;


* Unsubstitutable use of fuels in transportation sector

TRANS_D1(T)$(ord(T) > 1)..  E('A543') * X('A543',T) =G=
BASECOMP('A543') * D('N098',T);

TRANS_D2(T)$(ord(T) > 1)..  E('A548') * X('A548',T) =G=
BASECOMP('A548') * D('N099',T);

TRANS_D3(T)$(ord(T) > 1)..  E('A553') * X('A553',T) =G=
BASECOMP('A553') * D('N100',T);

TRANS_J1(T)$(ord(T) > 1)..  E('A546') * X('A546',T) =G=
BASECOMP('A546') * D('N098',T);

TRANS_J2(T)$(ord(T) > 1)..  E('A551') * X('A551',T) =G=
BASECOMP('A551') * D('N099',T);

TRANS_J3(T)$(ord(T) > 1)..  E('A556') * X('A556',T) =G=
BASECOMP('A556') * D('N100',T);

TRANS_G1(T)$(ord(T) > 1)..  E('A542') * X('A542',T) + E('A545') *
X('A545',T) =G= (BASECOMP('A542') + BASECOMP('A545')) *
D('N098',T);

TRANS_G2(T)$(ord(T) > 1)..  E('A547') * X('A547',T) + E('A550') *
X('A550',T) =G= (BASECOMP('A547') + BASECOMP('A550')) *
D('N099',T);

TRANS_G3(T)$(ord(T) > 1)..  E('A552') * X('A552',T) + E('A555') *
X('A555',T) =G= (BASECOMP('A552') + BASECOMP('A555')) *
D('N100',T);


* Feedstocks in chemicals, petrochemicals industry
FEEDST_1('A566',T)..  E('A566') * X('A566',T) =G= 0.4643 *
D('N104',T);
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```
FEEDST_2('A570',T)..  E('A570') * X('A570',T) =G= 0.4643 *
D('N105',T);

FEEDST_3('A574',T)..  E('A574') * X('A574',T) =G= 0.4643 *
D('N106',T);


GENCAPACITY(J,T)$(ElecAG(J)).. GENCAP(J,T) =E= (POWCAPINP(J) +
SUM(TT$(ORD(TT) lt ORD(T)),POWINV(J,TT) / ( MWHtoTOE * 8760 *
PFAC(J))))$(POWMODEL(J) = 1)
                                                + (POWCAPINP(J) +
SUM(TT$(ORD(TT) lt ORD(T)),POWINV(J,TT) / ( MWHtoTOE * 8760 *
PFAC(J))))$(POWMODEL(J) = 2)
                                                + (POWCAPINP(J) +
SUM(TT$(ORD(TT) lt ORD(T)), SUM(H$(HYDROARC(H) = ord(J)),
HYDROCAP(H)* OPENHYDRO(H,TT))))$(POWMODEL(J) = 3)
                                                + (POWCAPINP(J) +
SUM(TT$(ORD(TT) lt ORD(T)), OPENNUCLEAR(TT) * 1500))$(POWMODEL(J)
= 4);

MAXGENCAP_HC(T)$(ord(T) > 1)..  SUM(J$(ElecHC(J)), (GENCAP(J,T) -
GENCAP(J,T-1))) =L= (1500)$(ord(T) <= 8) + (1800)$(ord(T) > 8);

MAXGENCAP_L(T)$(ord(T) > 1)..   SUM(J$(ElecL(J)), (GENCAP(J,T) -
GENCAP(J,T-1)))  =L= (1500)$(ord(T) <= 8) + (1800)$(ord(T) > 8);

MAXGENCAP_D(T)$(ord(T) > 1)..   SUM(J$(ElecD(J)), (GENCAP(J,T) -
GENCAP(J,T-1)))  =L= (100)$(ord(T) <= 8) + (120)$(ord(T) > 8);

MAXGENCAP_FO(T)$(ord(T) > 1)..  SUM(J$(ElecFO(J)), (GENCAP(J,T) -
GENCAP(J,T-1))) =L= (100)$(ord(T) <= 8) + (120)$(ord(T) > 8);

MAXGENCAP_NG(T)$(ord(T) > 1)..  SUM(J$(ElecNG(J)), (GENCAP(J,T) -
GENCAP(J,T-1))) =L= (3000)$(ord(T) <= 8) + (3600)$(ord(T) > 8);

MAXGENCAP_W(T)$(ord(T) > 1)..   SUM(J$(ElecW(J)), (GENCAP(J,T) -
GENCAP(J,T-1)))  =L= (50)$(ord(T) <= 8) + (60)$(ord(T) > 8);

MAXGENCAP_G(T)$(ord(T) > 1)..   SUM(J$(ElecG(J)), (GENCAP(J,T) -
GENCAP(J,T-1)))  =L= (50)$(ord(T) <= 8) + (60)$(ord(T) > 8);

MAXGENCAP_H1(T)$(ord(T) > 1)..   SUM(H, OPENHYDRO(H,T)) =L= 2;

MAXGENCAP_H2(T)$(ord(T) > 1)..   SUM(J$(ElecH2(J)), (GENCAP(J,T) -
GENCAP(J,T-1)))  =L= (500)$(ord(T) <= 8) + (600)$(ord(T) > 8);

HYDROTIMING(H,T)$(Ord(T) < 3)..  OPENHYDRO(H,T) =E= 0;

NUCLEARTIMING(T)$(Ord(T) < 8)..  OPENNUCLEAR(T) =E= 0;

COST1(T)..  COSTACT(T) =E= SUM(J, C(J,T) * E(J) * X(J,T));

COST2(T)..  COSTINV(T) =E= SUM(J, ARCCAPC(J) * CAPINV(J,T))
                           + SUM(J, POWCAPC(J) * POWINV(J,T))
                           + SUM(J, POWVARC(J) * POWINV(J,T) +
```

```
POWFIXC(J) * OPENPLANT(J,T))
                             + SUM(H, HYDROCOST(H) *
OPENHYDRO(H,T))
                             + NUCLEARCOST * OPENNUCLEAR(T)
                             + R_CAPC * (REFINV1(T) + REFINV2(T) +
REFINV3(T) + REFINV4(T))
                             + CAPCTRANS_1_2 * TRANSINV12(T) +
CAPCTRANS_2_3 * TRANSINV23(T);


*NATIONAL(T)$(ord(T) >= 12).. SUM(J$(Domestics(J)), E(J) * X(J,T))
=G= SUM(J$(Imports(J)), E(J) * X(J,T));

X.fx('A111',T)= 0;
X.fx('A130',T)= 0;
P.fx('A111',T)= 0;
P.fx('A130',T)= 0;



MODEL ENERGY /ALL/;

option limrow=966;
option limcol=1;
option optcr=0;
option optca=0;


* Iteration limit for the solver
ENERGY.iterlim = 100000 ;
ENERGY.reslim = 100000 ;



SOLVE ENERGY MINIMIZING COST USING MIP;

*execute_unload "resultsmodel.gdx" X.L EMISSION.L GENCAP.L
*execute 'gdxxrw.exe resultsmodel.gdx var=X.L'
*execute 'gdxxrw.exe resultsmodel.gdx var=EMISSION.L
rng=Sayfa2!A1'
*execute 'gdxxrw.exe resultsmodel.gdx var=GENCAP.L rng=Sayfa4!A1'
```