A DECISION SUPPORT SYSTEM FOR ELECTRICITY GENERATION INVESTMENT

A THESIS SUBMITTED TO THE GRADUATE SCHOOL OF NATURAL AND
APPLIED SCIENCES OF MIDDLE EAST TECHNICAL UNIVERSITY

BY

MERİH AYŞE ALPAGUT

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY IN MINING ENGINEERING

JUNE 2010

Approval of the thesis:

A DECISION SUPPORT SYSTEM FOR ELECTRICITY GENERATION INVESTMENT

submitted by **MERİH AYŞE ALPAGUT** in partial fulfillment of the requirements for the degree of **Doctor of Philosophy in Mining Engineering Department, Middle East Technical University** by,

Prof. Dr. Canan Özgen ______________________
Dean, Graduate School of **Natural and Applied Sciences**

Prof. Dr. Ali İhsan Arol ______________________
Head of Department, **Mining Engineering Dept, METU**

Prof. Dr. Tevfik Güyagüler Supervisor, ______________________
Mining Engineering Department., METU

Examining Committee Members:

Prof. Dr. Çetin Hoşten ______________________
Mining Engineering Dept., METU

Prof. Dr. Tevfik Güyagüler ______________________
Mining Engineering Dept., METU

Prof. Dr. Naci Bölükbaşı ______________________
Mining Engineering Dept., METU

Prof. Dr. Neş'e Çelebi ______________________
Industrial Engineering Dept., Atilim University

Assist. Prof. Dr. Cenk Güray ______________________
Industrial Engineering Dept., Atilim University

Date: *30.6.2010*

I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

Name, Last name :

Signature :

ABSTRACT

A DECISION SUPPORT SYSTEM FOR ELECTRICITY GENERATION INVESTMENT

Alpagut, Merih Ayşe

Ph.D., Department of Mining Engineering

Supervisor: Prof. Dr. Tevfik Güyagüler

June 2010, 117 pages

In the recent years, ongoing debates in the mineral sector has shown that efficient use of natural resources is of vital importance as the use of minerals is essential for modern living. Especially, in the context of sustainable development, it is required that mineral resources should be exploited to maximize the contribution to the well being of current generation without depriving the potential for future generations to meet their own needs. The aim of this thesis is to develop a decision support system using system dynamics methodology where different generation scenario’s can be analyzed to determine the optimum generation capacity in Turkey. For this purpose, a system dynamics model of the Turkish electricity generation system is constructed and three scenarios are simulated on the proposed model: The first scenario estimates the electricity generation deficit, compares generation costs of all electricity resources and identifies lignite as the most economic resource to generate electricity from. Second scenario assumes that current shares of resources in electricity generation are preserved, and investigates depletion of lignite resources and emission generation under this assumption. Finally, in the third scenario, learning by doing in the renewable resource technologies is introduced to the model to incorporate effects of technological progress. The comparison of these scenarios has revealed that, currently, lignite is the most economical resource for electricity generation; however, electricity generation resources must be diversified to sustain secure electricity generation. The analyses of the scenarios have also shown that, investing in new technologies significantly increases energy efficiencies and decreases costs of these technologies, hence providing sustainable consumption of natural resources in terms of both emission generation and resource depletion.

Keywords: System dynamics, decision support system, electricity generation, learning by doing, resource depletion

ÖZ

ELEKTRİK ÜRETİM YATIRIMLARI İÇİN KARAR DESTEK MEKANİZMASI

Alpagut, Merih Ayşe

Doktora, Maden Mühendisliği Bölümü

Tez Yöneticisi: Prof. Dr. Tevfik Güyagüler

Haziran 2010, 117 sayfa

Son yıllarda maden sektöründe süregelen tartışmalar göstermiştir ki, doğal kaynakların efektif kullanımı, modern yaşamın sürdürülebilmesi açısından hayati önem taşımaktadır. Özellikle, sürdürülebilir kalkınma çerçevesinde, maden kaynaklarının işletilmesinin şimdiki kuşağa katkısının, gelecek kuşakların kendi ihtiyaçlarını karşılama potansiyeli göz önünde bulundurularak maksimize edilmesi gerekmektedir. Bu tezin amacı, sistem dinamiği yöntemi uygulanarak optimum elektrik üretim kapasitesini belirlemek amacı ile değişik senaryoların analiz edilebileceği bir karar destek mekanizması oluşturmaktır. Bu bağlamda, Türkiye elektrik üretim sisteminin sistem dinamiği modeli oluşturulmuş ve de önerilen model üzerinde üç senaryonun simulasyonu gerçekleştirilmiştir: İlk senaryo, elektrik üretim açığını hesaplamakta, farklı kaynakların elektrik üretim maliyetlerini karşılaştırarak, linyit kaynaklarını elektrik üretimindeki en uygun kaynak olarak belirlemektedir. İkinci senaryo, elektrik üretimindeki kaynakların mevcut paylarının korunduğunu varsaymakta, ve bu varsayım altında, linyit kaynaklarının tükenmesini ve emisyon oluşumunu irdelemektedir. Son olarak, üçüncü senaryoda, teknolojik gelişmelerin etkisini modele dahil etmek amacıyla yenilenebilir kaynakların teknolojilerinde yaparak öğrenme modele eklenmiştir. Bu senaryoların karşılaştırılması göstermiştir ki, şu anda linyit elektrik üretimi için en ekonomik kaynak olmakla birlikte, güvenli elektrik üretiminin sürdürülebilir olması için elektrik üretim kaynakları çeşitlendirilmelidir. Senaryo analizleri ayrıca yeni teknolojilere yapılan yatırımların enerji verimliliğini arttırdığını ve bu teknolojilerin maliyetlerini düşürerek, doğal kaynakların hem emisyon yayılımı hem de kaynakların tükenmesi bakımından sürdürülebilir olarak tükeilmesini sağladığını göstermiştir.

Anahtar Kelimeler: Sistem dinamiği, karar destek mekanizması, elektrik üretimi, yaparak öğrenme, kaynakların tükenmesi

TO MY FAMILY

ACKNOWLEDGEMENTS

I would like to express my sincere thanks to my supervisor Prof. Dr. Tevfik Güyagüler for his valuable contributions, scientific guidance, patience and encouragement in this study.

I would like to express my thankfulness to the examining committee members Prof. Dr. Çetin Hoşten and Prof Dr. Naci Bölükbaşı for their valuable suggestions and comments during the research. I would like to express my gratitude to Prof. Dr. Neş'e Çelebi for listening to my fuzzy ideas, and providing her scientific guidance, insight and encouragement, pushing me forward throughout the every phase of the research. I would like to thank Assist. Prof. Dr. Cenk Güray for his indispensable support, encouragement, friendship through all the good and dark times during the research and for making Maviş and Mahir dance with some good music.

I would like to thank Zeynep Arat for listening to me and proposing new ideas during various stages of my study. Prof. Dr. Gülin Birlik has supported me, and showed me that "I can" since the first statistics course I have taken, so thank you.

I would like to say thanks to Mesut Dal and Osman Karabay for helping me find the necessary data and providing hands on ground knowledge on the electricity generation sector.

It is not possible to conclude my acknowledgement without expressing my gratitude to my family: Evren, thank you for supporting my doctoral adventure from the very initial economics course till the end, thank you for being my project team member for life. Irmak, thanks for calming me down whenever I go crazy and being the elder sister for most of the time. Mom, thanks for fighting with me since the first day of my school life, I know it should have been some painful 28 years for you, thank you for your patience and love. I love you all.

TABLE OF CONTENTS

CHAPTERS

LIST OF TABLES

TABLES

LIST OF FIGURES

FIGURES

CHAPTER 1

INTRODUCTION

The essential role of energy in the modern world is unquestionable. It is the core of economic development, and hence the prosperity of the nations, since the industrial revolution. Historical data shows that the consumption pattern of energy always had an upward trend, and this tendency is not expected to cease in the near future. In fact, recent forecasts of International Energy Agency (IEA) indicate that total world demand in 2030 will be twice as today's demand, and China and India will be responsible for half of the total demand, together with the United States of America and the EU. Given this increasing energy demand, consumers who want to preserve their current consumption patterns are facing two new challenges in the energy sector: The first one of these challenges is about the global climate change, caused by consumption of hydrocarbons and the exhaustion of greenhouse gases into the atmosphere. The second problematic issue is assuring energy security, which is in depth more related with the abundance of natural resources from which energy is produced. According to IEA, if current energy consumption continues, the amount of greenhouse gases in the atmosphere will be twice as today's level in 2030, which will lead to a 6˚C increase in world's temperature. This figure is significant enough to get worried, considering all climate regime of the world will change. Although, India and China with the US will be accountable for most of the GHG in the atmosphere causing this change, the problem is global and every country will get affected from the climate change. Energy security, on the other hand, is also a global problem. Energy resources, especially hydrocarbons, are not distributed evenly around the world, and securing supply is the number one priority of governments. Oil prices are consistently increasing in last years, natural gas prices are bounded to oil price as well as international trade agreements, and even the price of coal which the most prevalent hydrocarbon resource is increasing. Considering this situation of global energy markets caused by the abundance of hydrocarbon minerals, it can easily be concluded that, the depletion of energy minerals play an important role in the energy policy of countries.

Turkey, who lies in a privileged geographic region, is directly affected from the above mentioned global picture. Despite her relatively less GHG emissions in the atmosphere, in 2007 Turkey's total GHG emissions are already twice of 1990 levels, with the current rate of growth and the energy production pattern, is not expected to decrease. As mentioned before, the problem is not local but global and Turkey has to take necessary precautions to decrease the amount of GHG in the atmosphere. Not only global climate change but also the global abundance of energy minerals is affecting Turkey, whose 67.2% of electricity production is met by hydrocarbon resources including oil, gas and coal (TEIAŞ, 2007). Despite this energy demand tableau, Turkey can be considered as a fairly poor country in terms of domestic energy minerals: Her only significant domestic energy resource is lignite and the deficit between energy demand and supply is met by imports. Hence, in order to regain and preserve her energy security, Turkey has to invest in exploration and production of domestic resources, as well as becoming an energy hub through international agreements, and make wise investments in energy sector towards the ultimate aim of constructing an independent energy policy. As one might easily observe, the straightforward answers to these to problematic issues generate a new paradigm, a new conflict of interest.

Today, there are almost 1.5 billion people on earth who don't have access to electricity, most of whom are living in developing countries like India, China and other under developed countries. This figure is not only huge but also is provoking when the rates of energy consumption and the living standards of the people in the developed countries are considered. While there is an enormous pressure on the governments to reduce their GHG emissions related with energy production, the developing countries definitely need energy to complete their industrialization process, bringing prosperity to their people, and the developed countries need energy to maintain their standards of living. In other words, development must be sustained to reach prosperity. Sustaining development requires sustaining energy production without further damaging the climate or the environment, for, unless the nature is preserved, in the final stage, mankind is doomed to vanish.

Today, although the potential of environment friendly renewable energy resources cannot be underestimated, it would not be wrong to say that utilization of these resources are far from meeting total energy demand and the consumption of fossil fuels which would emit more GHGs to the atmosphere is inevitable.

The solution of this dilemma mainly lies in development of new and environment friendly technologies in the energy sector. Recent researches on clean energy production have shown that, besides the potential of the renewable energies, opportunities for clean consumption of coal, especially in the electricity sector, are being developed. Among these technologies, carbon capture and storage (CCS) is especially promising in reducing the total GHG emissions. Fairly new electricity production technologies include Underground Coal Gasification (UCG) and Coal Bed Methane (CBM) production. Increasing energy efficiency and applying different carbon restriction policies, such as taxation and carbon trading are other means of decreasing total CO_2 emissions in the atmosphere.

Conceptual framework of this thesis is based on systems thinking. Systems thinking or system dynamics is an integrated assessment methodology that reflects the information feedback relationships of the complex systems. The methodology allows pure causal relationships (closed feedback loops) and delays to define the state of a system where an action within the feedback loop affects its surrounding, and this effect come back as information to influence further actions, changing the state of the system. A careful thinking would reveal that, most real world interactions have such information feedback relationships, and the concept of sustainable development in the energy sector whose underlying relations between energy, economy and environment are explained above, is no exception. In this regard, systems thinking is the methodology that allows seeing the bigger picture and interactions in the energy sector.

The aim of this thesis is to develop a decision support system for power plant investments in Turkey, where a balance between electricity generation, lignite consumption and GHG emission production is reached. When constructing the conceptual basis of this study, the natural resource abundance is also given a special importance, and a balanced consumption of domestic resources is anticipated.

After this brief introduction, the second part of this thesis comprises a literature survey on system dynamics modeling and different integrated assessment models of sustainable development after introducing the concept of sustainable development. The first set of models discussed in the literature solely deal with the GHG emissions and climate change problems. The second set of models, are models of resource abundance, and investment in minerals sector. Finally, the effect of technology in these models is investigated. After the current electricity market condition in Turkey is briefly overviewed in the third chapter. A system dynamics model based on the Turkish electricity generation system is constructed and explained in detail in Chapter 4 and finally, the model is simulated under three scenarios to evaluate potential electricity generation policies with respect to resource depletion and CO2 generation.

CHAPTER 2

LITERATURE REVIEW

2.1 Sustainable Development Overview

Sustainable Development is defined by the Brutland Commission as “development that meets the demands of the present without compromising the ability of future generations to meet their own needs.” Energy is the key to the sustainable economic development that enables relieving poverty, improving human welfare, and raising living standards, but no matter how important energy is for development, it is only a means to achieving good health and sustainable economy in a clean environment. Since electricity is the major input to economy, if the energy utilization is narrowed down to sustainable electricity generation, it would not be wrong to state that long run sustainable development can only be achieved when economic, social and environmental outcomes of development are balanced. Hence, sustainable development has three dimensions, economic, social, and environmental followed by an institutional dimension that involves agencies involvement in sustainability issues.

Social Dimension:

Energy availability has direct impact on human welfare, employment opportunities, pollution and health. While in rich countries, energy is clean, safe, reliable and affordable, in poor countries access to energy for heating or cooking purposes requires collecting wood and dung, with the potential of causing injury or disease through pollution generation and accidents. (IEA, 2005)

Economic Dimension:

All modern and developing economies rely on safe and adequate energy supply. Energy is the major input to the economy, and all economic sectors including residential, commercial, transportation, service, agricultural sectors use modern energy, affecting employment, productivity and development ().

Environmental Dimension:

Energy production, use, and distribution cause environmental problems in local and global levels. The environmental impacts depend greatly on the production and usage schemes of energy, the fuel mix, the structure of the energy systems, and related policies (IEA, 2005).

In order to measure sustainable development, energy indicators for sustainable development (EISD) has been developed by United Nations Department of Economic and Social Affairs, International Energy Agency, Eurostat and European Environment Agency. The purpose of developing energy indicators is to determine whether current energy use is sustainable and if not, how to improve it so that it is. Indicators are developed in the above mentioned three dimensions of sustainable development, providing information on current energy related trends and measuring progress towards the goals of sustainable development, so that a distinction between desirable and undesirable trends could be possible. Indicators do not only give an indication of the aspect of energy use but also help internalizing external costs (such as ill health and environmental damage) during policy making phase. Also, the indicators must be used as a means of tool which determines where to apply policy pressures and where to initiate changes that can bring desired results (IEA, 2005). Most indicators have linkages among themselves, and there exists causality relationships between the indicators.

2.2 Overview of System Dynamics

System dynamics is a methodology developed to reflect behavior of complex and dynamics systems, where the modeling effort is aimed at improving understanding between information-feedback structure and dynamic behavior of a system, so as to improve and develop policies to overcome problematic behavior. System dynamics models consist of a network of stocks and flows (levels and rates) where stocks represent the state of the system and flows define rate of conversion or changes in stocks.(Kelly, 1998; Forrester, 1961).

The underlying structure of the system dynamics models are the causal feedback relationships which define the behaviour of the system through causal loop diagrams: According to Haraldson(2004), the Causal Loop Diagram is a tool for systematically identifying, analyzing and communicating feedback loop structures. Utilization of stock and flow diagrams enables understanding processes as they are aiding tools for deriving differential equations. Figure 1 explains the dynamics of action-information and decision: All decisions made in order to take an action create further information on which the next decision is based.

Forrester (1992) state there are three components of decision making, namely desired state of affairs, identification of current state of the system, and generation of corrective decisions (policies) to take controlling measures (actions) to reach desired state of the system.

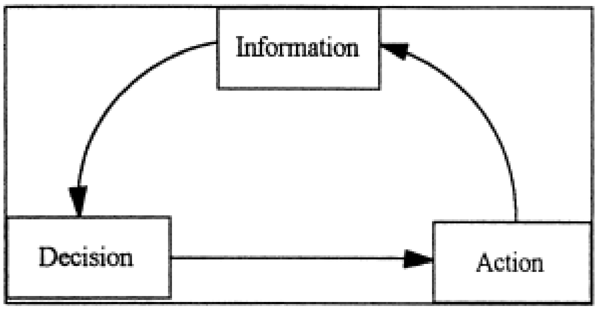


Figure 1. Relationship between decision-action-information which determines the behavior of a system (Forrester, 1961).

The three main elements of a system dynamics model are provided below:

i. Stocks or Level: These are the accumulations in the systems at the end of unit time dt.

If mathematically expressed:

Level(t)= ∫ (Rate of Inflow-Rate of Outflow) dt

ii. Rates or Flows: These are the flow of information and/or physical resources from level to level in a specified unit time, dt.

iii. Delays: These are the time delays taking place during transmission of information or physical resources. (Forrester, 1967)

In a most simplified form, the graphical representation of a system dynamics model is provided in Figure 2.

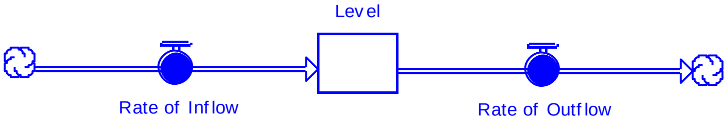


Figure 2. Graphical representation of a level and rate

While such a representation of the system facilitates the simulation process, without an effective understanding of the causal relationships and information-feedback characteristics in the system, it is unlikely that the constructed model will reflect the behavior of the system. Hence, causal loop diagrams define how the system operates. There are two kinds of causal loops:

i. Balancing feedback loops: Also known as negative feedback loops, these kind of relationship between system variables tend to bring the system into a balance, and denoted with (B or (-)) symbol in the diagrams.

ii. Reinforcing feedback loops: These types of loops are also called positive feedback loops. In such feedback relationships, system behavior is associated with an exponential increase or decrease, and this behavior is denoted with (R or (+)) symbol in the diagrams.

The system dynamics model in this work is built in system dynamics software STELLA, version 6.0 for Windows. The software calculates the values of levels in discrete time segments, delta time or DT.

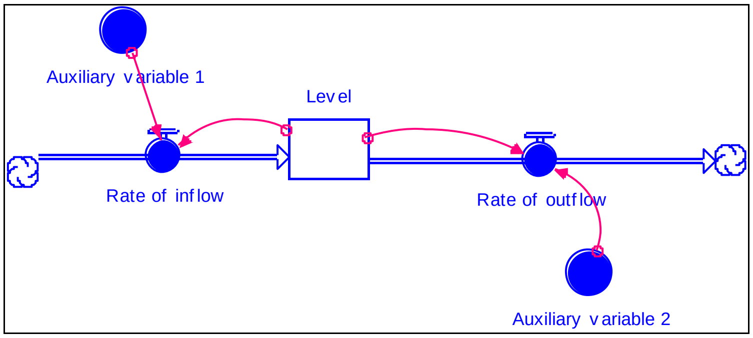


Figure 3. System dynamics representation of system variables

The schematic model representation of Figure 3 stands for the following set of equations in STELLA:

- Level(t) = Level(t - dt) + (Rate_of_inflow - Rate_of_outflow) * dt
- INIT Level = 0
- Rate_of_inflow = Auxiliary_variable_1*Level
- Rate_of_outflow = Auxiliary_variable_2*Level

Solving the equations in the software involves a two step initialization phase and three step evaluation phase (STELLA, 2000) and these steps are described below:

“**INITIALIZATION PHASE:**

Step 1. Create a list of all equations in required order of evaluation.

Step 2. Calculate initial values for all stocks, flows and converters (in order of evaluation).

ITERATION PHASE:

Step 1. Estimate the change in stocks over the interval dT. Calculate new values for stocks based on this estimate.

Step 2. Use new values of stocks to calculate new values for flows and converters.

Step 3. Update simulation time by an increment of DT. Stop iterating when Time >= simulation To Time.” (STELLA, 2000)

The motive behind utilization of system dynamics modeling in this work is as follows: According to the definition of Sustainable Development, the two main issues in the supply of energy for the welfare of the current and future generations are, energy resources’ scarcity and environmental pollution caused by energy consumption. Traditional energy modeling fails to address behavior of competitive energy industry due to lack of feedback structure and linear nature (Bunn & Dyner, 1996). In order to overcome this situation, most models investigating energy-environment interactions are integrated assessment models: Integrated assessment models of sustainable development mainly investigate energy-economy-ecosystem-technology-climate systems in a highly simplified manner, and often their integrated representation of these systems come from the global system dynamics models of the 70s such as the world model of Forrester (1971) and Limits to Growth (Meadows et al, 1972). These models can help evaluating potential responses to energy utilization-resource consumption-environmental pollution by describing and comparing costs, benefits, impacts and other consequences of specific responses of energy utilization and relevant environment degradation. The models provide a framework for structuring present knowledge about environmental, social and economic stresses and serve to advance basic knowledge and understanding. Hence, based on the above mentioned reasons, system dynamics is applied in this work because complex systems whose parameters are interconnected could be best represented in models where the system is simulated as a whole. The following section will compromise a number of integrated climate-economy models in the literature, identify the major parameters in the model, and the choice of their policy approaches.

2.2.1 Models of Emissions, Energy and Economic Growth

a) Dynamically Integrated Climate-Economy Model (DICE)

Dynamically Integrated Climate-Economy model, is a global, dynamic neo-classical optimal growth model where a single producer-consumer tries to maximize the present value of utility by choosing between the levels of current consumption, investment and reducing GHG emissions (Nordhaus, 1992), The major purpose of the model is to calculate the marginal damage of a ton of carbon emissions over time, to evaluate policies of mitigation. In the model, losses in the production are caused by emission abatement and climate changes. The energy sector is not detailed in terms of emissions; however an abatement cost function, in which 1% of output is the cost of reducing emissions by half from their unconstrained level, is fitted statistically to the estimates of former studies.

b) Regional Integrated Model Of Climate And The Economy (RICE)

The RICE model, or Regional Integrated model of Climate and the Economy, derived from DICE, is a regional, dynamic, general-equilibrium model of the economy which integrates economic activity with the sources, emissions, and consequences of greenhouse-gas emissions and climate change (Nordhaus and Yang, 1996). In the model, world is divided into sub-regions, each having an initial capital stock, population and technology. The model treats population and technology exogenously, while capital stock accumulation takes place through capital flows endogenously. Economic output function in the model is Cobb-Douglas function in capital, labor and technology; and the preference function of each region is the utility function. Climate change is linked to the model through CO_2 emissions, equations of global concentration and global climate change. Other emissions than CO_2 emissions are considered to be exogenous, and all emissions are accepted to be a slowly declining fraction of gross output. CO_2 emissions are controlled by altering the CO_2 intensive parameters, such as the output prices and the cost of CO_2 abatement is estimated from studies on CO_2 reduction costs, while the economic impacts of climate change are assumed to be increasing with the realized temperature change. The policy choices undertaken by the nations in the model are market policies (no controls on GHGs), cooperative approaches (all nations work with the common goal of reducing emissions), and non cooperative approaches (each nation care for their self national interests, whereas economical preferences of the nations are consuming all goods and services, investing in productive capital and slowing climate change by reducing CO_2 emissions.

c) Targets Image Energy (TIME) Model

TIME model is the energy module of TARGETS model, an integrated assesment model of global change, developed by Dutch National Institute for Public Health and the Environment. The model uses system dynamics as the integrated assessment methodology and Energy module. TIME consists of five sub modules, Demand, Electric Power Generation, and the supply of Solid (SF), Liquid (LF),and Gaseous (GF) Fuels . The aim of the module is to analyze the long-term dynamics of energy conservation and the transition to non-fossil fuels. The model makes use of bottom up engineering approach to simulate the dynamic behavior of the system, whilst linking macroeconomic indicators to the rest of the economy. The main three determinants in the Energy demand sub model are changing activity patterns, products, and processes (‘structural change’); autonomous increases in energy productivity (‘Autonomous Energy Efficiency Improvements’ or AEEI); and energy productivity changes in response to changes in fuel and electricity prices (Jannsenn & de Vries, 2000). End-use demand is investigated according to whether it causes structural changes in the market (technology changes) or not(residential use, transportation, etc.). End-use demand is affected by the population and structural change. AEII is also a factor influencing the total demand, due to the fact that energy intensity decreases with the increasing efficiency.

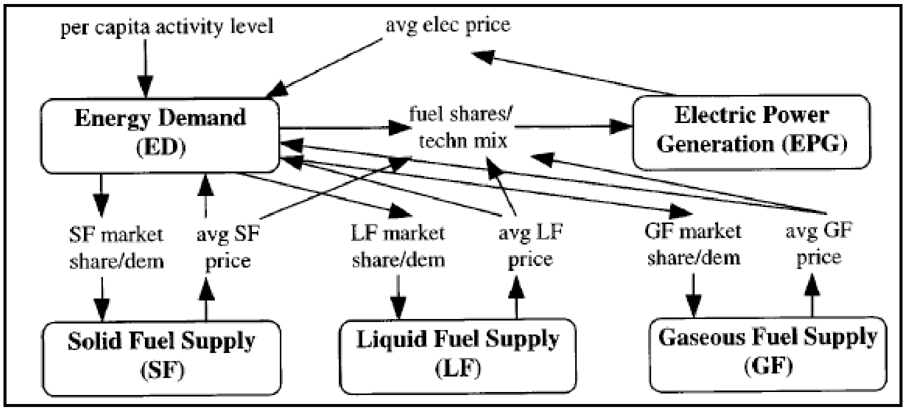


Figure 4 The structure of TARGETS model

Price Induced Energy Efficiency Improvement(PIEEI) , which depends on prices and market shares of secondary fuels , is another factor affecting the end-use demand , due to its direct linkage to supply cost curve.

Electric Power Generation sub model (EPG) foresees the demand for electricity and reflects this foresight to the establishment of new capacity or the expansion of existing capacity with a delay. The electricity production is achieved through thermal, hydro and non thermal resources.

The model has three fossil submodels, for solid, liquid and gaseous fossil fuels. As being non renewable resources, all these fossil fuels have certain amount of reserves and certain cumulative production. The resource-reserve conversion takes place after exploration and feasibility phases, depletion multiplier and learning parameter affect the overall condition of the reserves such that the former depletes the reserves when exploıted and the latter reduces the capital-output ratio with a learning parameter.

The solid fuel submodel deals with coal production, which is decided to be invested in upon the demand forecast. The model identifies between surface and underground mining according to the stripping ratio. Investments in mining add to the capital stocks, and hence directly influence the capital-output ratio. In underground mining, capital-output ratio increases due to depletion and high labour costs, while in surface mining, economies of scale and technological developments decrease the capital-output ratio . The coal price is defined as the product of coal capital costs, an overhead factor, and a factor that takes supply-demand imbalances into account. In response to an excess or shortage of capacity , the coal price changes. The changes in the capacity also influence the revenues and in turn generates with a delay of investments.

The other two sub models, namely oil and gas, calculate the forecast of required production with an overhead factor covering the exploitation and processing/transport of energy use. The model also takes into account the energy losses occurred during processing and transportation. The capital depreciates and additional investment is required for production with a delay. The average price of crude oil and gas is the product of capital costs, an overhead factor, and a supply-demand multiplier. The case of biofuels is also investigated incorporating production function with capital, labor, and land as production factors both for Liquid (LBF) and Gaseous (GBF) biofuels.

The climate sub module estimates the impacts of greenhouse gas effects on the environment as well as reflecting the element cycles and the interactions between the chemical elements in the biosphere.

The constructed model is used to simulate four different scenarios; the first one being the baseline scenario where the energy consumption triples, the second scenario accelerates the technological development in the supply side, leading to a decrease in energy costs. The third scenario increases the technological development in the demand side of the energy resources, decreasing energy intensities through increasing energy efficiencies. The fourth and the final scenario is a combination of the second and third scenarios.

d) Feedback Rich Energy-Economy Model (FREE)

The model constructed by Fiddaman(1997) is a system dynamics model that investigates the relationship between energy-environment and economy, and reflects these relationships through complex information feedback structure. The model is based on early work of Nordhaus. The major difference of the model from the previous ones is that it contains a higher degree of feedback loops with increasing degree of complexity.The model assumes economies of scale, and despite previous models, endogenizes tehcnological change with a positive feedback loop (learning by doing). The production function used in the model is Cobb Douglas with exogenous forecasts for factor productivity, population and AIEE. The sector boundary of the model is given in Figure 5.

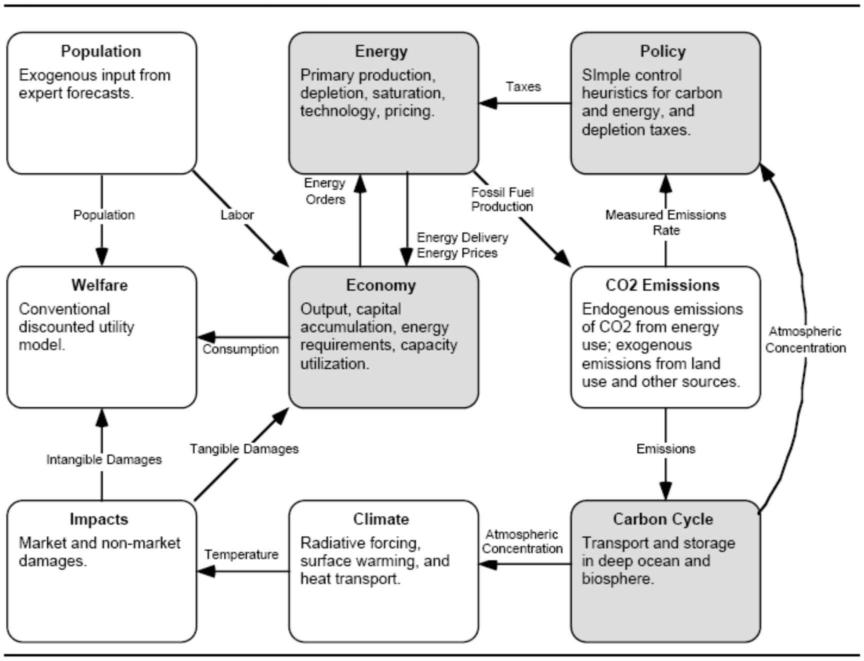


Figure 5. Sector Boundary of FREE (Fiddaman, 1998)

The model also tries to maximize human welfare through the concept of discounted cumulative utility, the discounted utility being a function of population, rate of time preference and utility. The results of climate damage is embedded in utility function through the share of environmental services in the utility function.

e) Emissions Predictions and Policy Analysis (EPPA)

Emissions Predictions and Policy Analysis (EPPA) model is an computable general equilibrium model of global coal consumptionin relation to CO2 emissions. The study is conducted by a group of interdisiplinary researchers at MIT. Under alternative economic assumptions, the study aims to identify behavioral responses of theenergy system to various changes in technology, efficiency increase , switching to low carbon emitting resources or carbon free energy technologies. In this sense, the study investigates power plant technologies as a important strategy to reduce CO2 emissions. Carbon Capture and Storage (CCS) is also considered to be a serious alternative for zero emissions technologies altough its commercial applications is not widely utilized due to high costs and the CO2 storage problems .

The study is significant in terms of evaluating different electricity generation technologies in terms of CO2 capture and capital, operating and maintenance costs. The basic assumption of the study is that the electricity generating units were greenfield units which contained all the emissions control equipment.

2.2.2 Models of Resource Consumption and Energy Demand

Discussions on the scarcity of resources go back to 18th century, when Thomas Maltus declared that population would run out of food supply, leading to a decrease in food per person, based on the idea that population would increase on geometric rate while the food increases on an arithmetic rate. More recent work has been developed by Meadows et al (1972) in Limits to Growth, which uses a system dynamics model to show the collapse of per capita food and industrial development as a result of depletion of energy resources. In Beyond the Limits (Meadows et al , 1992) however, the discussion changes in the sense that natural resource abundance rather causes environmental damages and the depletion of energy resources is irrelevant. Tilton (1996) explains this two existing polarizations as fixed stock paradigm and opportunity cost paradigm. The fixed stock paradigm proposes that the limited stocks of the resources will diminish at some point in time through the excessive consumption caused by increasing population. Increasing demand will increase the prices and the developments in technology will not help increasing the stocks enough to meet the demand. Furthermore, the advances in the technology will lead to further consumption, causing environmental problems such as thinning of ozone layer and global warming. Due to the failure of internalizing the environmental costs associated with these environmental problems, market will overproduce and the resources will deplete. On the other hand, the opportunity cost paradigm suggests that the resources are not fixed and many generations can use them. The market equilibrium will ensure that when production costs increase due to limited availability of limited resources, the demand will decrease. Moreover, the advances in technology will reduce production costs. The relevant costs are assumed to be the full opportunity costs that include the technology and environmental costs. The high prices caused by these costs will lead to development of new technologies, and all relevant costs will be internalized then.

a) Long term perspectives on world metal use

Long term perspectives on world metal use (van Vuuren, Strengers, & de Vries, 1999), a system dynamics model on sustainable development. Model is based on Tilton's theory of two paradigms, investigates sustainable world metal use in relation to population and economic growth on one hand and consequences of energy and capital requirement and waste flows on the other hand. The model makes use of a system dynamics model for this purpose, and the system is characterized by two major loops. In the higher level model, geological resources are converted into reserves by exploration activities, ore extracted from reserves is used to produce refined metals or metal compounds (primary production). Metals after this point either slowly dissipate or dumped in places where they could be recycled(secondary production), or disposed directly. Consumption of the metals is defined as the sum of competing primary and secondary production, metal use (demand) is defined as a function of GDP per capita. Future primary production is described by the interplay of technological development and ore grade decline. The long term feedback loop deals with the tradeoff between depletion (decline in the ore grade) and learning dynamics (learning by doing it), where production costs equal energy costs (technological development in exploitation affects energy and capital costs) plus capital costs and exploration costs. Learning by doing it, stands for gaining know-how, and there exists a log-linear relationship between cumulative production and efficiency of processes for different engineering applications through knowledge accumulation. In the short-term loop, investments in primary mineral production, mining and producing capital in response to market shortages and expected profits defined.

The abundance of the natural resources is the core of this work and the environmental issues related with energy consumption is not discussed in detail. However, the role of investment and in the research for new reserves, and the effect of technological development is well underlined in this study.

b) Using system dynamics to model interaction between environment and economical factors in the mining industry

Another study trying to assess the natural resource abundance in a broader context is “Using System Dynamics to model interaction between environment and economical factors in the Mining industry” (O'Regan & Moles, 2006). The purpose of the study is to investigate the supply side of the minerals industry in relation with investments to the minerals sector. Supply-demand relationships within the minerals market is designated as shown in Figure 5. The model is constructed using an integrated assessment approach, the utilized methodology being system dynamics.

The decision of investment of the mining firm is directly related to international mineral markets and the prices, as well as the economic condition of the country and the governments' environmental policies (Figure 6). There are various time delays between the investment in exploration plan and ending up with proven reserves, and with proven reserves and marketable commodity.(Figure 7, Figure 8)

2.2.3 Incorporating Technological Progress into the Models

Technology has been augmented in integrated assessment energy models by a variety of methods, namely, carbon emissions reducing, cost reducing and output augmenting. The improvement in energy technologies can be reflected in energy models through increase in autonomous energy efficiencies exogenously or by learning by doing, endogenously (Parson &Fisher-Vanden, 1997).

Most models dealing with energy-environment-technology interactions are based on neo-classical theory of economic growth to represent technological change. The major pitfall of these representations is that they treat technology as an exogenous factor, the representation of technological and structural change is difficult and the assumption of constant elasticities of substitution under technological change is not realistic

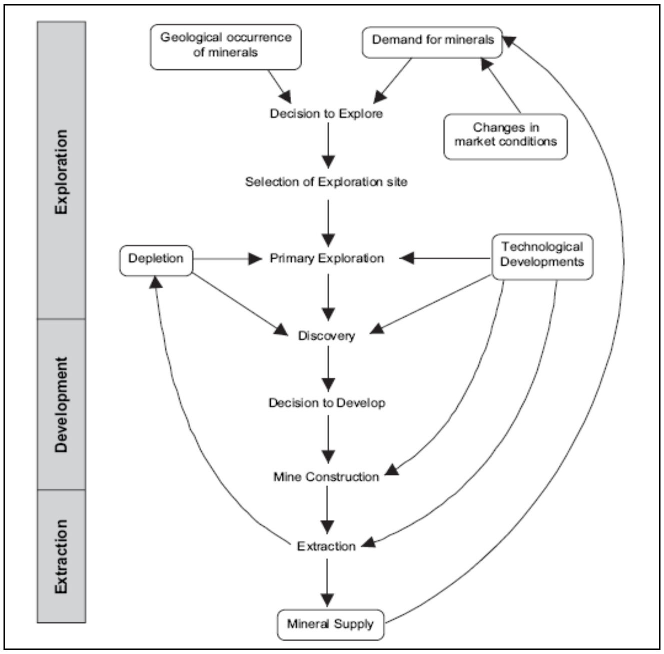


Figure 6 Mineral Supply to the markets (O'Regan and Moles, 2006)

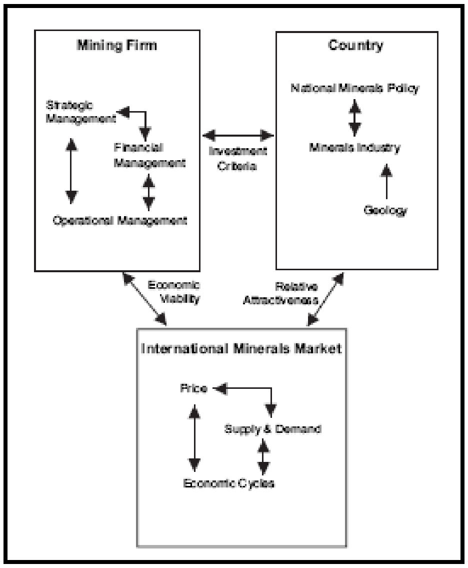


Figure 7 The sector map (O'Regan and Moles, 2006)

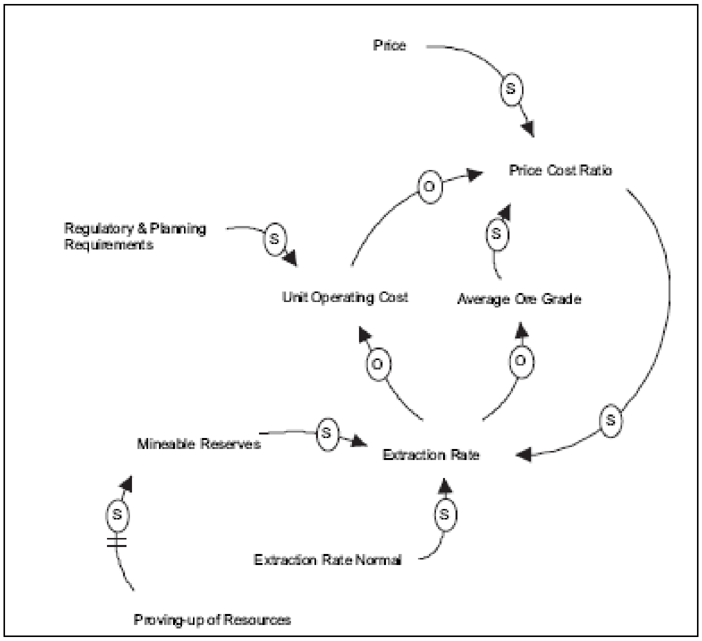


Figure 8 Resources to marketable commodity (O'Regan and Moles, 2006)

Also, when technological progress is incorporated into the models autonomously, the technological change will arrive out of nowhere, in other words, the processes where invention and innovation will be disregarded and technology diffusion will occur directly.

On the other hand, endogenising technical progress will allow for representing invention and innovation processes. Utilization of learning curves (learning-by-doing) is the most widely applied methodology to represent the endogenous technological change.

a) Learning-by-doing

The effects of learning by doing was first observed in the manufacturing s and industrial sectors, when it was understood that production costs decrease as the level of production increases (Jamasb & Köhler, 2008).

Manne & Richels(2004) define learning-by-doing (LBD) as the process in costs of new technologies decline by the cumulative experience, and the accumulation of the production experience leads to an rapid technological progress for energy sources. In other words, the deployment or utilization of the technology increases the experience in that technology, resulting in the optimization of the technology employed (Ferioli et al., 2009).

The performance of new emerging technologies is best measured by the price of that technology, which is directly influenced by learning through market experience. Learning reduces prices for various energy technologies affecting the competition between different technologies in turn. A learning curve is then defined by the equation:

$$C(X_t)= C(X_o)\ (X_t/X_o)^{-b} \qquad \text{(Equation 1)}$$

Where

"X_0" is the cumulative production.

"Xt" is cumulative production/capacity in year t.

$C(X_o)$ is the cost of production/capacity at time 0

$C(X_t)$ is the cost of production/capacity at time t "b" is the (positive) experience parameter, which characterizes the inclination of the curve. Large values of b indicate a steep curve with a high learning rate (IEA, 2000).

Generally, learning rates are estimated by fitting historical data cost and production data to Equation 1 above. Comparisons between different experience curves are made by doubling the cumulative volume and the corresponding change in price is referred to as the progress ratio (PR).

The learning rate (LR) is then defined as

LR= 100 — Progress Ratio

or

$LR= 1-2^{-b}$(IEA, 2000). (Equation 2)

Whenever the new technology's price equals the older technologies price (break- even point), the new technology is competitive. Figure 9 shows on a double-logarithmic scale the relationship between capacity deployment and price, e being the learning rate. Furthermore for new technologies entering the market, the breakeven capacity X_b is the required cumulated production to reach the cost target at which the technology becomes competitive and learning investment, I, becomes the additional cost for reaching the break-even price (Figure 10) (Ferioli et al, 2009). The initial gap between the new technology and the older one is closed by additional costs, or the learning investments. The experience curve does not indicate when the technology will become feasible.

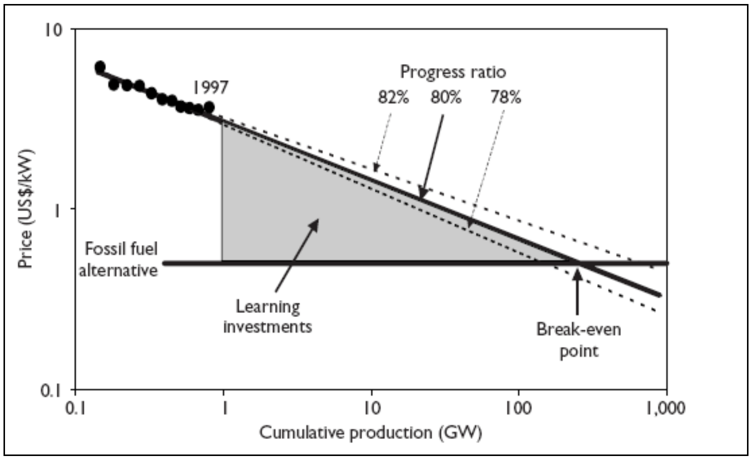


Figure 9 Breakeven point and learning investments for photovoltaic modules with a progress ratio of 80% (IEA, 2000)

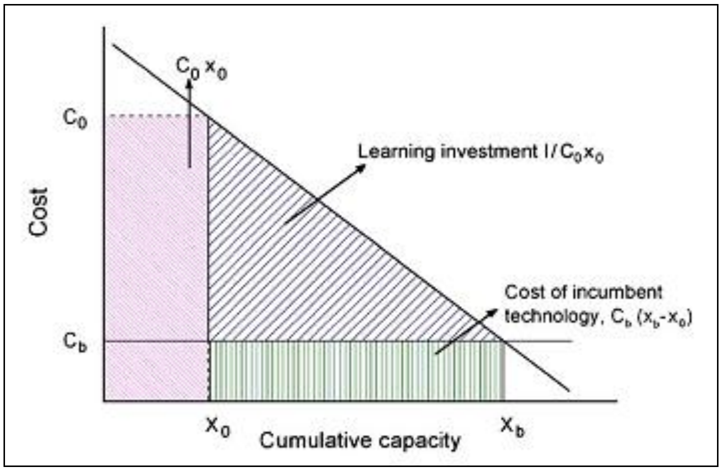


Figure 10. Required learning investment to reach the breakeven price ((Ferioli, Schoots, & van der Zwaan, 2009)

In energy technology practice, however, the learning rate does not only depend on cumulative experience but also depends on the retirement rate of existing technologies due to the capital intensity of energy investments and future demand expectations. Also, it is noted in a number of research that learning rates of conventional methods are lower than those of novel technologies (Manne & Barreto, 2004; IEA, 2000): The study by OECD/IEA has shown that the learning rates for wind energy and photovoltaic cells are much higher compared to IGCC or coal plant learning rates (Figure 11).

Energy related learning rates are tried to be assessed in a number of studies. McDonald and Schrattenholzer (2001), estimated learning rates for 26 electricity generation technologies, assuming that cost reductions are a function of a specific experience parameter(Figure 12). Reported energy related learning rates are also reflected in the same study

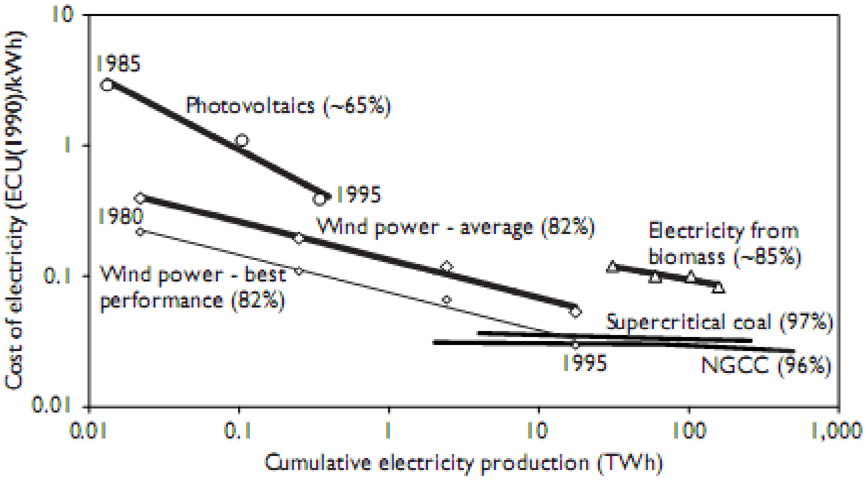
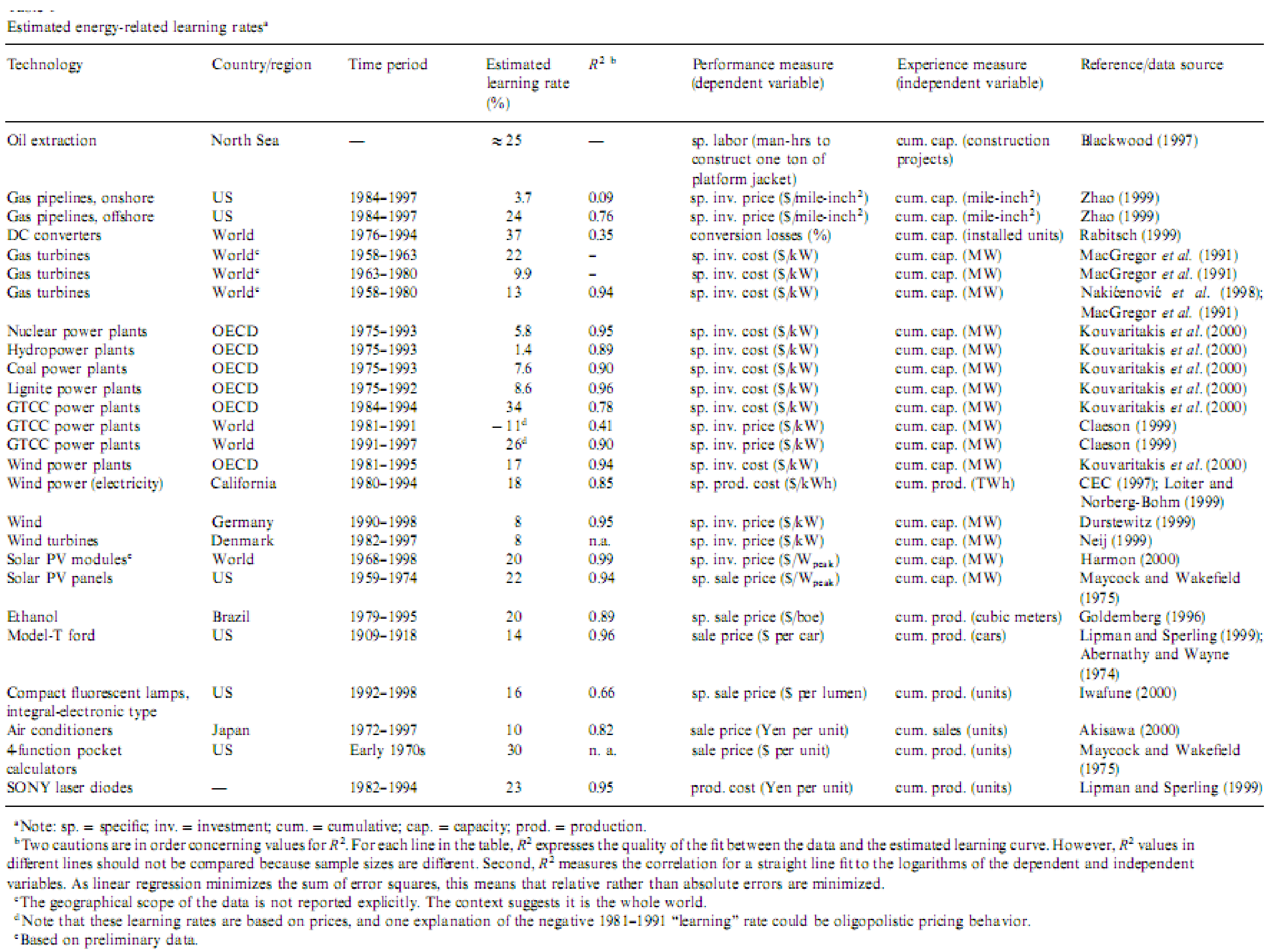


Figure 11. Electric Technologies in EU, 1980-1995

.

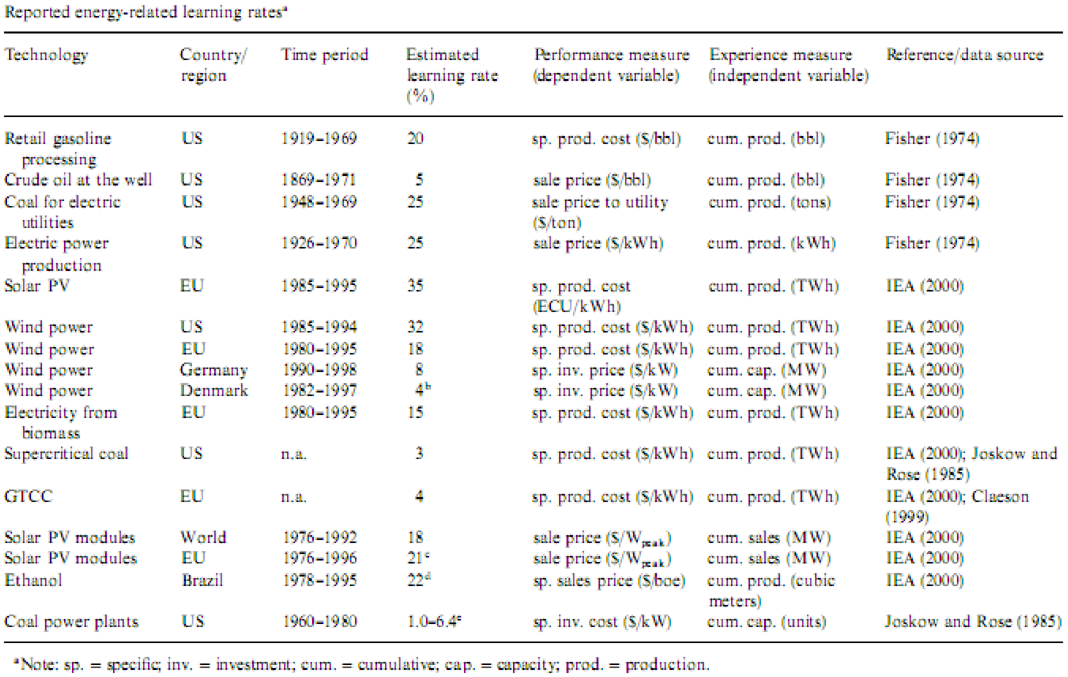


Estimated energy-related learning rates[a]

Technology	Country/region	Time period	Estimated learning rate (%)	R^2 [b]	Performance measure (dependent variable)	Experience measure (independent variable)	Reference/data source
Oil extraction	North Sea	—	≈ 25	—	sp. labor (man-hrs to construct one ton of platform jacket)	cum. cap. (construction projects)	Blackwood (1997)
Gas pipelines, onshore	US	1984–1997	3.7	0.09	sp. inv. price (\$/mile-inch^2)	cum. cap. (mile-inch^2)	Zhao (1999)
Gas pipelines, offshore	US	1984–1997	24	0.76	sp. inv. price (\$/mile-inch^2)	cum. cap. (mile-inch^2)	Zhao (1999)
DC converters	World	1976–1994	37	0.35	conversion losses (%)	cum. cap. (installed units)	Rabitsch (1999)
Gas turbines	World[c]	1958–1963	22	-	sp. inv. cost (\$/kW)	cum. cap. (MW)	MacGregor *et al.* (1991)
Gas turbines	World[c]	1963–1980	9.9	-	sp. inv. cost (\$/kW)	cum. cap. (MW)	MacGregor *et al.* (1991)
Gas turbines	World[c]	1958–1980	13	0.94	sp. inv. cost (\$/kW)	cum. cap. (MW)	Nakićenović *et al.* (1998); MacGregor *et al.* (1991)
Nuclear power plants	OECD	1975–1993	5.8	0.95	sp. inv. cost (\$/kW)	cum. cap. (MW)	Kouvaritakis *et al.* (2000)
Hydropower plants	OECD	1975–1993	1.4	0.89	sp. inv. cost (\$/kW)	cum. cap. (MW)	Kouvaritakis *et al.* (2000)
Coal power plants	OECD	1975–1993	7.6	0.90	sp. inv. cost (\$/kW)	cum. cap. (MW)	Kouvaritakis *et al.* (2000)
Lignite power plants	OECD	1975–1992	8.6	0.96	sp. inv. cost (\$/kW)	cum. cap. (MW)	Kouvaritakis *et al.* (2000)
GTCC power plants	OECD	1984–1994	34	0.78	sp. inv. cost (\$/kW)	cum. cap. (MW)	Kouvaritakis *et al.* (2000)
GTCC power plants	World	1981–1991	− 11[d]	0.41	sp. inv. price (\$/kW)	cum. cap. (MW)	Claeson (1999)
GTCC power plants	World	1991–1997	26[d]	0.90	sp. inv. price (\$/kW)	cum. cap. (MW)	Claeson (1999)
Wind power plants	OECD	1981–1995	17	0.94	sp. inv. cost (\$/kW)	cum. cap. (MW)	Kouvaritakis *et al.* (2000)
Wind power (electricity)	California	1980–1994	18	0.85	sp. prod. cost (\$/kWh)	cum. prod. (TWh)	CEC (1997); Loiter and Norberg-Bohm (1999)
Wind	Germany	1990–1998	8	0.95	sp. inv. price (\$/kW)	cum. cap. (MW)	Durstewitz (1999)
Wind turbines	Denmark	1982–1997	8	n.a.	sp. inv. price (\$/kW)	cum. cap. (MW)	Neij (1999)
Solar PV modules[e]	World	1968–1998	20	0.99	sp. inv. price (\$/W_{peak})	cum. cap. (MW)	Harmon (2000)
Solar PV panels	US	1959–1974	22	0.94	sp. sale price (\$/W_{peak})	cum. cap. (MW)	Maycock and Wakefield (1975)
Ethanol	Brazil	1979–1995	20	0.89	sp. sale price (\$/boe)	cum. prod. (cubic meters)	Goldemberg (1996)
Model-T ford	US	1909–1918	14	0.96	sale price (\$ per car)	cum. prod. (cars)	Lipman and Sperling (1999); Abernathy and Wayne (1974)
Compact fluorescent lamps, integral-electronic type	US	1992–1998	16	0.66	sp. sale price (\$ per lumen)	cum. prod. (units)	Iwafune (2000)
Air conditioners	Japan	1972–1997	10	0.82	sale price (Yen per unit)	cum. sales (units)	Akisawa (2000)
4-function pocket calculators	US	Early 1970s	30	n. a.	sale price (\$ per unit)	cum. prod. (units)	Maycock and Wakefield (1975)
SONY laser diodes	—	1982–1994	23	0.95	prod. cost (Yen per unit)	cum. prod. (units)	Lipman and Sperling (1999)

[a] Note: sp. = specific; inv. = investment; cum. = cumulative; cap. = capacity; prod. = production.
[b] Two cautions are in order concerning values for R^2. For each line in the table, R^2 expresses the quality of the fit between the data and the estimated learning curve. However, R^2 values in different lines should not be compared because sample sizes are different. Second, R^2 measures the correlation for a straight line fit to the logarithms of the dependent and independent variables. As linear regression minimizes the sum of error squares, this means that relative rather than absolute errors are minimized.
[c] The geographical scope of the data is not reported explicitly. The context suggests it is the whole world.
[d] Note that these learning rates are based on prices, and one explanation of the negative 1981–1991 "learning" rate could be oligopolistic pricing behavior.
[e] Based on preliminary data.

Figure 12. Estimated energy related learning rates (McDonald & Schrattenholzer, 2001)



Reported energy-related learning rates[a]

Technology	Country/ region	Time period	Estimated learning rate (%)	Performance measure (dependent variable)	Experience measure (independent variable)	Reference/data source
Retail gasoline processing	US	1919–1969	20	sp. prod. cost ($/bbl)	cum. prod. (bbl)	Fisher (1974)
Crude oil at the well	US	1869–1971	5	sale price ($/bbl)	cum. prod. (bbl)	Fisher (1974)
Coal for electric utilities	US	1948–1969	25	sale price to utility ($/ton)	cum. prod. (tons)	Fisher (1974)
Electric power production	US	1926–1970	25	sale price ($/kWh)	cum. prod. (kWh)	Fisher (1974)
Solar PV	EU	1985–1995	35	sp. prod. cost (ECU/kWh)	cum. prod. (TWh)	IEA (2000)
Wind power	US	1985–1994	32	sp. prod. cost ($/kWh)	cum. prod. (TWh)	IEA (2000)
Wind power	EU	1980–1995	18	sp. prod. cost ($/kWh)	cum. prod. (TWh)	IEA (2000)
Wind power	Germany	1990–1998	8	sp. inv. price ($/kW)	cum. cap. (MW)	IEA (2000)
Wind power	Denmark	1982–1997	4[b]	sp. inv. price ($/kW)	cum. cap. (MW)	IEA (2000)
Electricity from biomass	EU	1980–1995	15	sp. prod. cost ($/kWh)	cum. prod. (TWh)	IEA (2000)
Supercritical coal	US	n.a.	3	sp. prod. cost ($/kWh)	cum. prod. (TWh)	IEA (2000); Joskow and Rose (1985)
GTCC	EU	n.a.	4	sp. prod. cost ($/kWh)	cum. prod. (TWh)	IEA (2000); Claeson (1999)
Solar PV modules	World	1976–1992	18	sale price ($/$W_{peak}$)	cum. sales (MW)	IEA (2000)
Solar PV modules	EU	1976–1996	21[c]	sale price ($/$W_{peak}$)	cum. sales (MW)	IEA (2000)
Ethanol	Brazil	1978–1995	22[d]	sp. sales price ($/boe)	cum. prod. (cubic meters)	IEA (2000)
Coal power plants	US	1960–1980	1.0–6.4[e]	sp. inv. cost ($/kW)	cum. cap. (units)	Joskow and Rose (1985)

[a] Note: sp. = specific; inv. = investment; cum. = cumulative; cap. = capacity; prod. = production.

Figure 13. Reported learning rates (McDonald & Schrattenholzer, 2001)

While the learning rates in McDonald and Schrattenholzer (2001) were explained with two variables (cumulative production/sales and price/cost), the effect of R&D on learning rates remained vague. Kahouli-Brahmi (2008) suggest that learning rates cannot solely be explained by price/cost and cumulative production, as R&D investments also influence final production costs (Figure 14). Learning rates for two factor learning curves are calculated by Jamasb and Köhler (2008) (Figure 15).

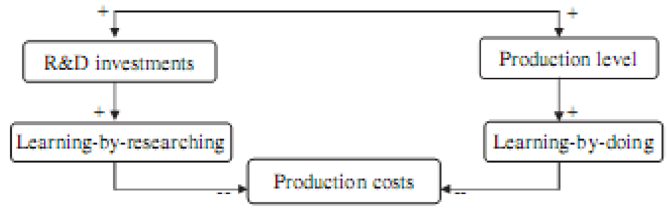
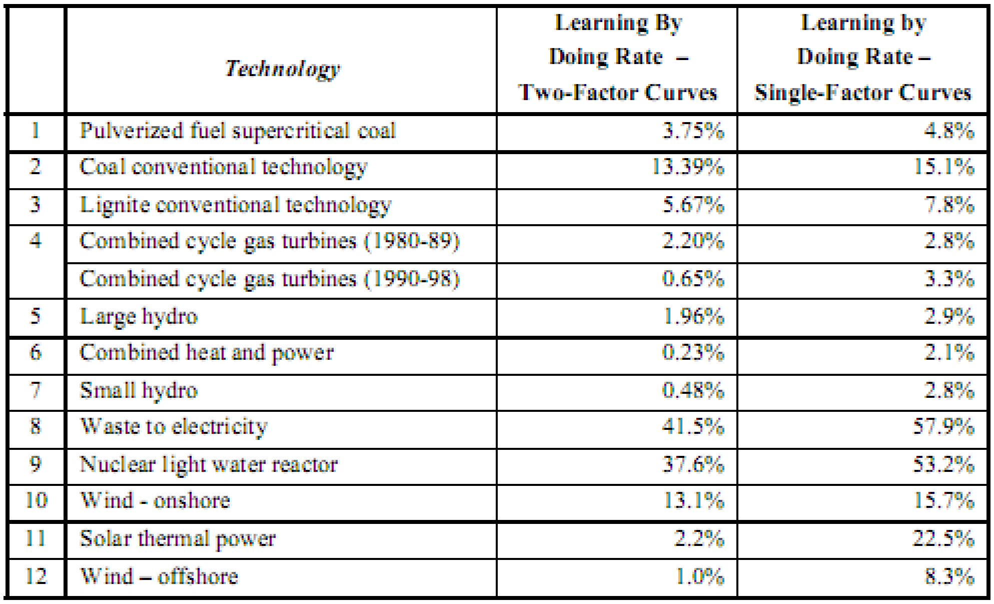


Figure 14. Feedback relationship between R&D investments, learning by doing and production costs ((Kahouli-Brahmi, 2008).



	Technology	**Learning By Doing Rate – Two-Factor Curves**	**Learning by Doing Rate – Single-Factor Curves**
1	Pulverized fuel supercritical coal	3.75%	4.8%
2	Coal conventional technology	13.39%	15.1%
3	Lignite conventional technology	5.67%	7.8%
4	Combined cycle gas turbines (1980-89)	2.20%	2.8%
	Combined cycle gas turbines (1990-98)	0.65%	3.3%
5	Large hydro	1.96%	2.9%
6	Combined heat and power	0.23%	2.1%
7	Small hydro	0.48%	2.8%
8	Waste to electricity	41.5%	57.9%
9	Nuclear light water reactor	37.6%	53.2%
10	Wind - onshore	13.1%	15.7%
11	Solar thermal power	2.2%	22.5%
12	Wind – offshore	1.0%	8.3%

Figure 15. Learning rate calculations for two factor curves (Jamasb & Köhler, 2008)

The aim of this thesis work is to build an integrated assessment model to develop a means to model coal production in Turkey, provided that Turkey will sustain its economic development with an optimal use of its natural resources, natural resources being both fossil fuel reserves, and environment. Technology is the key element in the model, for mitigating environmental effects of fossil fuel consumption. Introduction of learning curves to describe the effect of technology in economy allows reflecting the progress in technology, as well as effectively endogenising its effect in the behaviour of the system. The integrated assessment of energy, environment and technology will be established through system dynamics modeling, which allows reflecting the dynamic and feedback characteristics of such complex systems. System dynamics is a methodology that makes use of stock and flow diagrams that defines the state of the system, causal loop diagrams which define interrelations among system parameters and differential equations. Once such a model is built, the policies required to achieve a sustainable development of Turkish lignite reserves for electricity generation will be investigated, ensuring that the national and international environmental regulations for air qualities and CO2 emissions are obeyed. Incorporation of other energy sources such as natural gas, oil and renewable energy resources (wind, solar, hydro, geothermal) to the model is also required since they form an important portion of the fuel mix from which electricity is generated and play an important role in Turkey's energy policies. Technologies allowing for mitigation of the greenhouse effect are those that allow for more efficient firing of fossil fuels and those that directly aim to minimize flue gases such as carbon capture and storage (CCS) and the other available technologies. Control over the model will be achieved by the indicators of sustainable development, ie whenever one of the indicators exceed the pre-defined maximum limit, system will try to reduce it by applying suitable policies.

CHAPTER 3

OVERVIEW OF TURKISH LIGNITE AND ELECTRICITY SECTORS

3.1 Share of Fuels in Electricity Generation and Development of Electricity Demand

The development of Turkish electricity market and capacity projections is regularly reported by TEIAS (General Directorate of Turkish Electricity Transmission Company).

Table 1 shows the growth in Turkey's peak electricity and energy demand between years 1999-2008. While electricity demand has shown continious growth over the years, in 2001, the electricity demand decreases from 8,30% in 2000 to -1,1%, due to the 2001 financial crisis.

Table 1.Peak Electricity Demand and Energy Demand of Turkish Electric System Between 1999-2008 (TEIAŞ, 2009)

	Peak Electricity Demand (MW)	Growth (%)	Energy Demand (GWh)	Growth (%)
1999	18.938,00	6,40	118.485,00	3,90
2000	19.390,00	2,40	128.276,00	8,30
2001	19.612,00	1,10	126.871,00	-1,10
2002	21.006,00	7,10	132.553,00	4,50
2003	21.729,00	3,40	141.151,00	6,50
2004	23.485,00	8,10	150.018,00	6,30
2005	25.174,00	7,20	160.794,00	7,20
2006	27.594,00	9,60	174.637,00	8,60
2007	29.249,00	6,00	190.000,00	8,80
2008	30.517,00	4,30	198.085,00	4,20

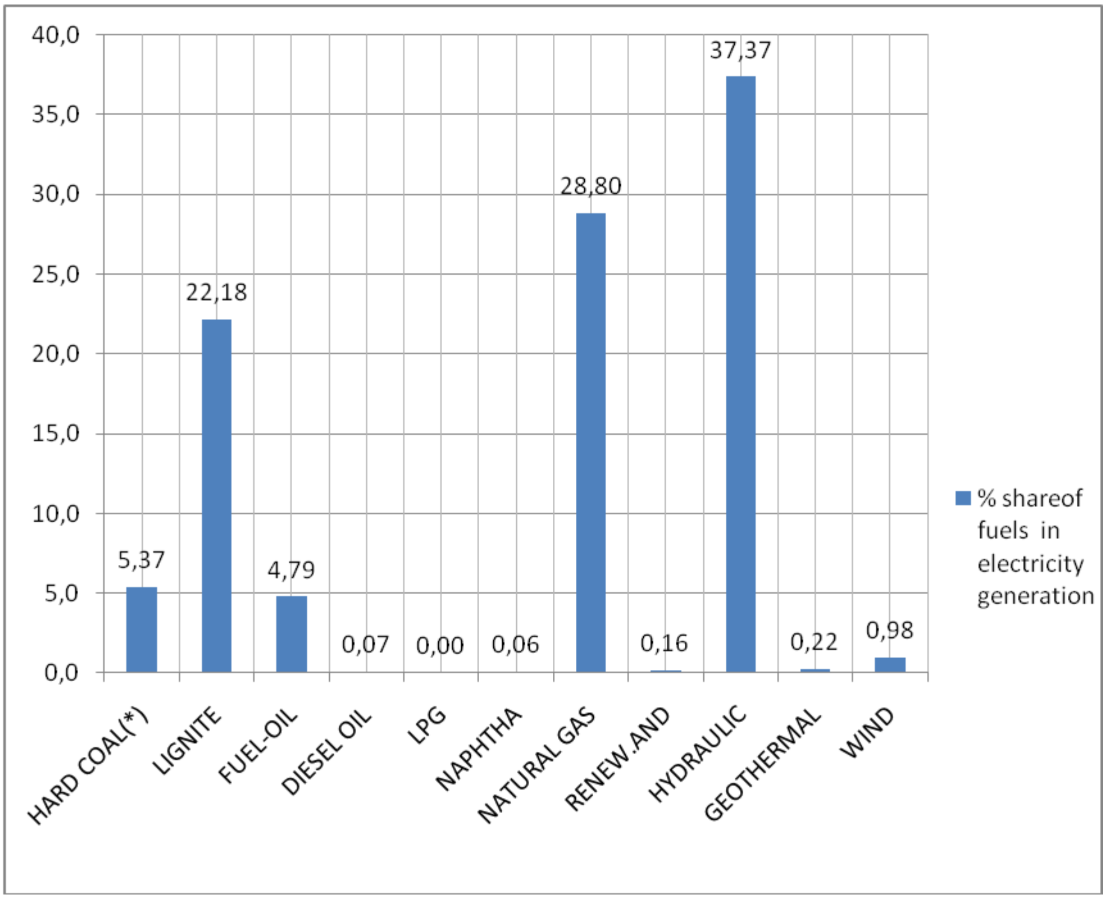


Figure 16. Share of fuels in electricity generation (TEIAS, 2009)

As can be observed from Figure 16 above, natural gas is the dominating fuel in electricity generation with 25.48% share in overall fuel mix, followed by lignite with 19.62 % share and 4.7% share of hard coal. Among the renewable resources, hydro is the major resource with 33% share in electricity generation.

3.2 Turkish Lignite Reserves

Turkish lignite reserves are mainly being operated by TKİ. The amount of possible, probable and proven reserve estimations is provided in Table 2.

Table 2. Turkish lignite reserves in 2004

ESTABLISHMENTS			RESERVES(1000 Ton)				
			Possible	Probable	Proven	Ready	Total
GELİ	GELİ	Eskihisar			43,435	874	44,309
		Tınaz			30,893	173	31,066
		Bağyaka			8,069		8,069
		Taşkesik			51,843		51,843
		Bayır			26,431		26,431
		Turgut			6,165		6,165
		Total			166,836	1,047	167,883
	YLİ	Sekköy			27,342	665	28,007
		İkizköy			74,632	209	74,841
		Hüsamlar			82,07	1,85	83,92
		Karacahisar			85,77		85,77
		Total			269,814	2,724	272,538
	Establishment Total				**436,65**	**3,771**	**440,421**
SLİ	SLİ	Seyitömer			162,783	8,877	171,66
	BLİ	Orhaneli			38,746	246	38,992
		Keles			27,897	110	28,007
		Davutlar	1,56	19,945	17,557		39,062
		Total	1,56	19,945	84,2	356	106,061
	Establishment Total		**1,56**	**19,945**	**246,983**	**9,233**	**277,721**
GLİ	GLİ	Tunçbilek			309,29	1,465	310,755
	ILİ	Ilgın			8,322	985	9,307
	Establishment Total				**317,612**	**2,45**	**320,062**
ELİ	ELİ	Soma		6,3	94,023	4,866	105,189
		Deniş		11	174,88	5,342	191,222
		Eynez	22,439	60,2	202,125	880	285,644
		Total	22,439	77,5	471,028	11,088	582,055
	ÇLİ	Çan			89,515	100	89,615
	Establishment Total		**22,439**	**77,5**	**560,543**	**11,188**	**671,67**
CONTROL DEPARTMENTS	Adana-Tufanbeyli			23,684	190,476		214,16
	Konya-Beyşehir				81,011	71	81,082
	Çankırı-Orta				50,71		50,71
	Tekirdağ-Saray			105,57	23,581		129,151
	Bolu-Göynük			1	37,927		38,927
	Bingöl-Karlıova				88,221	441	88,662
	Silopi(Asfaltit)		1	16,21	32,04		49,25
	Şırnak (Asfaltit)		6,3	13,26	11,013		30,573
	Other Fields		5,308	24,573	69,297	56	99,234
	Total		**12,608**	**184,297**	**584,276**	**568**	**781,749**
T K İ T OTAL			**36,607**	**281,742**	**2.146.064**	**27,21**	**2.491.623**
TEAŞ	K.Maraş-Elbistan				4.311.000		4.311.000
	Sivas-Kangal				168,439		168,439
	Ankara-Çayırhan		15	83	265,176		363,176
	Total		**15**	**83**	**4.744.615**		**4.842.615**
****Private Sector+MTA**			415,308	497,631	1.111.693		2.024.632
TOTAL (Excluding TKI)			**430,308**	**580,631**	**5.856.308**		**6.867.247**
TOTAL TURKEY			**466,915**	**862,373**	**8.002.372**	**27,21**	**9.358.870**

Table 3. Chemical properties of Turkish lignite reserves

ESTABLISHMENTS			CHEMICAL PROPERTIES				
			Moisture	Ash (%)	Sulphur (%)	Volatile Material %	Calorific Value (Kcal/kg)
GELİ	GELİ	Eskihisar	40	20	3	27	2070
		Tınaz	32	29	2,3	25	2070
		Bağyaka	38	26	1,3	25	1790
		Taşkesik	30	24			2660
		Bayır	26	24	2,8	31	2670
		Turgut	39	21	3,1		2130
		Total					
	YLİ	Sekköy	34	26	3,2	29	2190
		İkizköy					
		Hüsamlar	30	33	3,1	28	1650
		Karacahisar	28	28	4,3		2260
		Total					
		Establishment Total					
SLİ	SLİ	Seyitömer	32	43	1,2	22	2080
	BLİ	Orhaneli	24	24	2	34	2500
		Keles	34	26	1,5	26	1900
		Davutlar	31	26	4,5		2340
		Total					
		Establishment Total					
GLİ	GL	Tunçbilek	15	41	1,6	25	2560
	ILİ	Ilgın	50	11	1,1	26	2180
		Establishment Total					
ELİ	ELİ	Soma	15	36	1,2	26	2940
		Deniş	18	40	1,2	20	2080
		Eynez	13	33	1,3	27	3150
		Total					
	ÇLİ	Çan	23	25	4,2	30	3000
		Establishment Total					
CONTROL DEPARTMENTS	Adana-Tufanbeyli		44	26	2,2	20	1350
	Konya-Beyşehir		48	25	1,1	17	1110
	Çankırı-Orta		48	26	0,6	17	1090
	Tekirdağ-Saray		45	16	1,9	20	2080
	Bolu-Göynük		24	26	1,8	25	2750
	Bingöl-Karlıova		47	24	0,6	16	1460
	Silopi(Asfaltit)		6	31	4	30	5310
	Şırnak (Asfaltit)		6	31	4,5	39	5330
	Other Fields						
	Total						
TKİ TOTAL							
TEAŞ	K.Maraş-Elbistan		51	21	1,5-2	19	1130
	Sivas-Kangal		48-52	19-21	3	20	1280
	Ankara-Çayırhan		20	38	4	25	2370
	Total						
TOTAL TURKEY							

3.3 Renewable Energy Potential in Turkey

3.3.1 *Solar Potential*

Turkey has a high solar energy potential with respect to its geographical location, with a yearly average total of sunlight duration is 2.640 hours (~7,2 hours/day) and average total radiation intensity is 1.311 kWh/m²-year (3,6 kWh/m² per day). As a result, the solar energy potential in Turkey is calculated as 380 billion kWh/year.

Solar energy technologies are diversified by means of the methods applied, materials used and level of the technology adapted. Solar energy systems diverge into two main groups:

- Concentrating Solar Power (CSP): Solar concentration allows tailored design approaches for central and distributed power generation. The heat generated by these systems can either be directly used or utilized for electricity generation.
- Solar Cells (Photovoltaics - PV): Sunlight is directly turned into electricity with the help of semiconducting materials.

The main disadvantage of solar cells is the high cost of production by use of polycrystalline or amorphous silicon and thin film technologies all of which are currently in the markets.

With the decrease of the manufacturing costs and increase in productivity, the utilization of solar cells is expected to become more widespread in parallel with the manufacturing of such PV systems in Turkey.

The amount of established solar collectors in Turkey is 12 million m² and the technical solar energy potential is 76 tons of oil equivalent (toe). On the other hand, annual production volume is 750.000 m², some amount of which is currently exported. The amount of usage per capita is assumed to be 0,15 m² with these figures. The annual thermal energy production from the solar collectors is around 420.000 toe In this state, Turkey is one of the foremost producers and users of solar collectors in the world.

The established power of solar cells has reached to 1 MW in Turkey, majority of which is found in government institutions used for meeting low power requirements and/or research purposes.

3.3.2 Wind Energy

Wind energy is formed by the displacement of air mass having different temperatures. The 1,2% of the energy arriving earth from the sun is turned into wind energy. The wind turbines transform the renewable air flow into electric energy. Since the operation of wind turbines do not lead to an emission of environmentally-noxious gases, they have an important role on the future energy resources and prevention of climate change.

Contrary to the conventional power plants, the wind energy is a continuously useable and domestic energy source that eliminates the risks of fuel costs and long-term fuel prices in terms of energy security and reduces the dependency to the other countries in terms of economic, political and procurement risks. The main disadvantages of the wind turbines are counted as the high volume occupation, noise pollution formation and the quality of the electricity generated.

The world wind source capacity is calculated as 53 TWh/year, and total established wind energy power is 40.301 MW. One-third of this capacity is installed in Germany. The amount of investment for reaching 1,245 GW world wind power target in 2020 is 692 billion Euro. In this respect, the production costs is expected to drop down to 2,45 Euro-cents/kWh from 3,79 E-cents/kWh. It is estimated that 8 billion Euro of current business volume in the wind turbine markets will increase globally to 80 billion Euro in 2020. In the meantime, it’s possible to make feasible wind energy investments with present prices in the regions having total potential minimum capacities of 48.000 MW and yearly average minimum speed of 7,5 m/s.

According to the Turkey Wind Energy Potential Atlas – 2007 (REPA), there is a capacity of 5.000 MW in the regions where the wind speed is above 8,5 m/s, and a capacity of 45.000 MW in the regions where the speed is above 7,0 m/s.

While the established wind energy power was 18 MW in 2004, established power has increased to 802,8 MW in 2009. After the Renewable Energy Law has come into force, 93 new wind energy project licenses with an established capacity of 3.363 MW were assigned. Among these assigned licenses, the construction of wind energy plants with a established capacity of 1.100 MW is ongoing.

Table 4. The domestic potential of wind energy in 2008

Source Type	**Domestic Potential**
Wind	HighProductivity: 8.000 MW,
	Medium Productivity: 40.000 MW

3.3.3 Geothermal Energy

Geothermal energy is the thermal energy attained by the transfer of heat collected in the rocks underground by the flow and storage of fluids in the reservoirs. Thermal energy is generated by naturally formed hot water and steam, and/or by use of dry red-hot rocks in an artificial way. Geothermal sources are generally formed around the active fracture systems and volcanic and magmatic units.

Geothermal energy for electricity production is regarded as clean energy with respect to its low emission of undesirable gases (CO_2, NO_x, SO_x).

Geothermal energy can be used either directly or indirectly in terms of the temperature attained from the geothermal source. Direct uses of geothermal energy are appropriate for sources below 150^0C. Low temperature regions (20-70°C) are used for space heating, air conditioning, industrial processes and drying. Medium (70-150°C) and high (above 150 °C) temperature regions are valued as electricity production and integrated heating applications depending on the re-injection conditions.

By reason of being on the Alp-Himalaya zone, Turkey has a quite high geothermal potential, estimated as 31.500 MW. The leading regions are concentrated more in Western Anatolia with 77,9 %. However, currently 13% of that potential (4.000 MW) is ready for use in the country.

It is stated that 55% of Turkey’s geothermal regions are appropriate for heating applications. Some of these sources are generally used for greenhouse and house heating applications. Between 2003-2009, Mineral Research and Exploration Institute (MTA) discovered some more regions that have 840 MW potential capacity (Ministry of Energy and Natural Resources, 2010).

1.500 MW of Turkey's geothermal potential is estimated to be appropriate for electricity production. The proven capacity is 600 MWe at present (Ministry of Energy and Natural Resources, 2010)

3.4 Structure of the Electricity Market

Turkish electricity market law (EML, No: 4628), aiming to establish competitive and transparent market structure, came into force in 2001. With the enforcement of the Law, Turkish electricity market is re-structured, and the following legal and institutional framework was introduced.

- An Energy Market Regulatory Authority (EMRA),
- Licensing framework,
- Energy market, based on bilateral contracts, and
- Freedom for consumers to choose their suppliers.

The Electricity Sector Strategy Paper, introduced in 2004, provides a roadmap for the sector reform, and next to bilateral contracting, a balancing and settlement mechanism is developed, for the establishment of a spot market and signals to attract new investment.

In general, electricity market structures can be classified as single price market models and dual price model. Single price market models are real-time balancing markets which are mostly controlled by the government, and electricity generation is rarely based on bilateral contracts. The major drawback of single market models is that they lack demand side participation. On the other hand, dual price models, next to being real time balancing markets, also receive demands from a day ahead. Bilateral contracts are a major influential factor over the market, and market operation is provided by market operators and system operators. Market operators regulate the financial (years ahead) and spot (day ahead) electricity market while system operators regulate instantaneous electricity demands on the delivery day.

3.4.1 Current Electricity Market Structure In Turkey

In Turkey, Built-Operate (BO), Built-Operate-Transfe r(BOOT), and Transfer of Operating Rights (TOOR) investments were encouraged after 1999, increasing the share of private sector in electricity generation from 20% in1999 to 45% in 2006. Private sector mainly chose to invest in thermal plants and BO and TOOR type of electricity generations were granted the right of purchase guarantee for their whole electricity generation, while the purchase guarantee of BOT type of investments were remained at 85%. Due to this regulation, the purchase guarantee granted plants are prioritized in electricity generation, and have an important share in meeting peak demand.

At the moment Turkish electricity market is a single price market, run by bilateral contracts and balancing market, whereas the sectoral reform in the market aims at;

- Bilateral contracts markets between market participants
- An organized day-ahead market – operated by market operator (TEİAŞ)
- A real-time system balancing and operational mechanism by the system operator (TEİAŞ, NLDC)
- One or more organized markets for procurement of ancillary services (transmissions)
- Organized market for financially settled electricity contracts *(*Erdoğdu, 2010).

Turkey targets dual price market model due to

- demand-side participation in dual price models
- price verification is much easier
- a local resource utilization optimization leads to innovation and optimal planning
- introduced risk management
- competitive market where price is determined by marginal price.

Currently, most producers prefer to sell their electricity in spot markets due to high prices in the spot market. In Turkish electricity market, there is supply shortage, however in healthy competitive markets, there should be surplus capacity where the price is negotiated.

CHAPTER 4

AN INTEGRATED ASSESSMENT MODEL FOR SUSTAINABLE ELECTRICITY PRODUCTION

Economic development cannot be separated from energy production and consumption. However, both energy production and consumption has consequences in terms of sustainability: Keeping in mind that the share of renewable energy resources (including hydro) in total primary energy supply is only 12.9 % in the world (IEA, 2008), and that the remaining portion of energy demand is met by fossil fuel consumption, the first restriction for sustaining energy consumption is the abundance of hydrocarbon minerals. Hence it can be stated that finite hydrocarbon resources is one aspect of sustainability whilst on the other hand the consumption of these resources lead to significant environmental problems due to emissions of greenhouse gases and other particulates. These environmental effects are the second major restriction on sustainability, as they directly influence human welfare and economic development.

The integrated assessment model for sustainable electricity production aims to reflect the effect of these two major sustainability issues in electricity generation: Resource Supply and Environmental Effects.

Electricity can be produced from a variety of resources including lignite, natural gas, hydro power, renewable energy resources (wind, geothermal and solar) and nuclear energy. However, for the sake of simplicity, supply of hydrocarbon resources in electricity production is restricted to coal supply; from the very initial stage of exploration to production. Assuming a competitive market for energy resources, electricity generation from lignite resources compete with electricity generation from other resources such as natural gas, hydro and renewables, in terms of both economic viability and environmental effects, which are the two other aspects of sustainable development.

Therefore, to analyze the variables affecting the energy production based on lignite, and to make long run plans and projects, the construction of an appropriate model is needed.

In this regard, the model to be constructed consists of Coal Supply Sector, Electricity Generation Sector, Other Thermal Generation Capacity Sector, Emissions Sector, and Renewable Energy Sectors in the high level. The linkages between these sectors are dynamic and they carry information-feedback characteristics (Figure 17). In the Figure, R denotes reinforcing, B denotes balancing feedback loops.

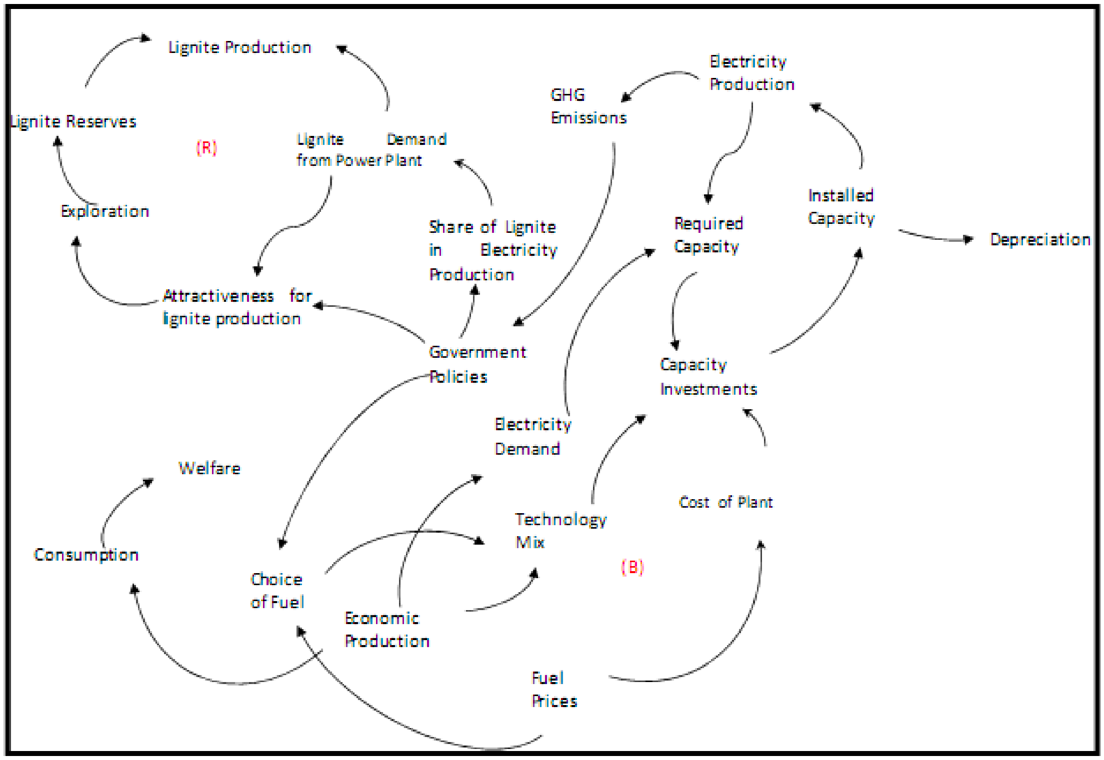


Figure 17. High level causal loops in the model

4.1 Lignite Supply Module

The aim of lignite supply module is to select the most suitable lignite resource available in terms of lignite quality, exploit and explore this most favorable site for further development opportunities. The dynamics of lignite exploration and resource development process is shown in Figure 18 .

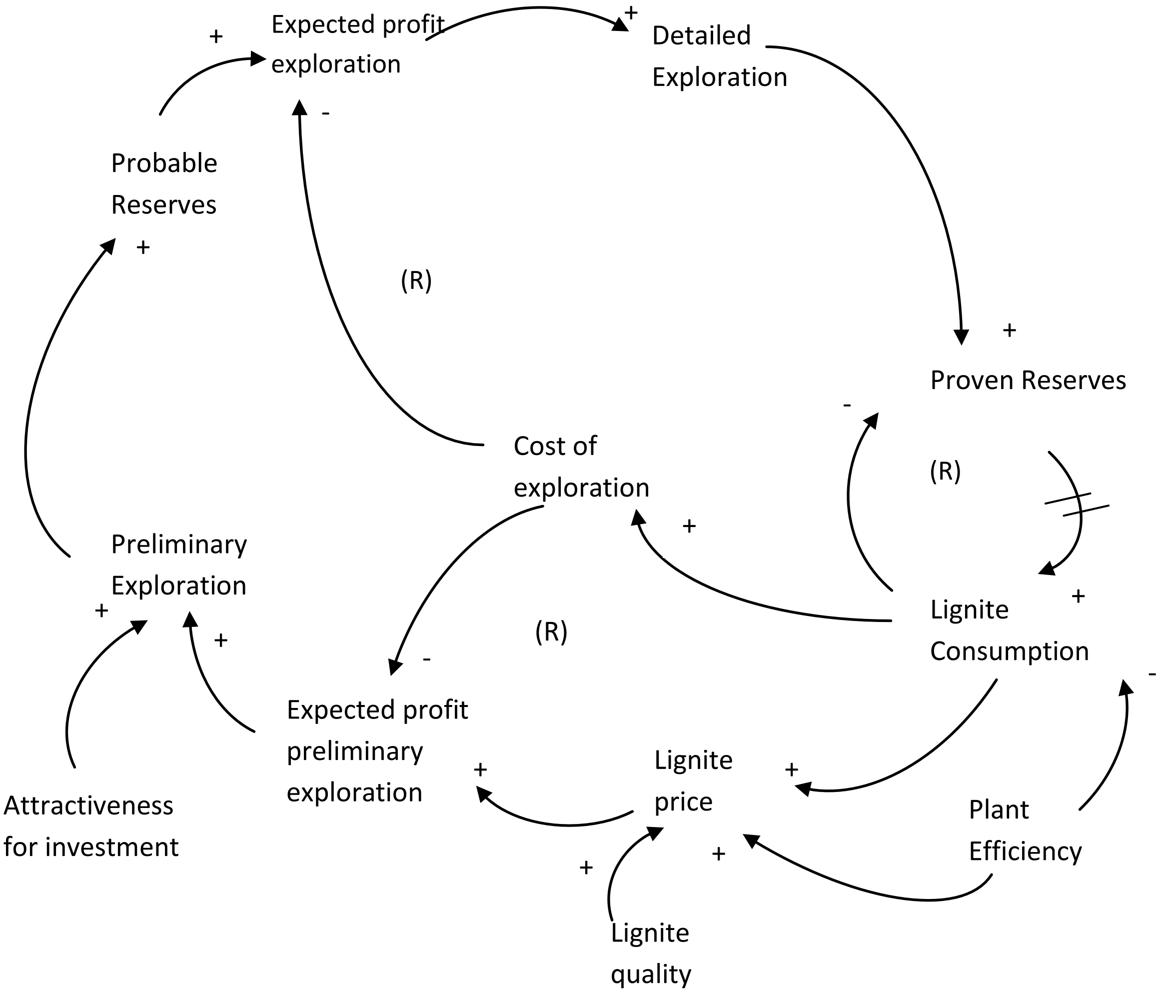


Figure 18. Dynamics of mineral exploration

As can be seen from Figure 18 above, the quality of the lignite and efficiency of the plant in which lignite are the effective variables to determine the price of the lignite, which in turn affects the expected revenue along with the cost of exploration. Since investment decisions depend on expected profit, the decision to perform a preliminary exploration is based on whether or not expected the investment results in profit at the end of preliminary exploration. Attractiveness of the region to investors in terms of legal and environmental legislation applications also is a factor influencing exploration decision of the investors. Hence, given that a profit expectation at the end of preliminary exploration occurs at a discount rate of 12% and that the region attracts mineral investors; the decision to conduct a preliminary exploration is taken. Pursuant to successful completion of preliminary exploration activities, the possible reserves can be estimated with a higher accuracy level and detailed exploration is done with similar considerations of profit and regional attractiveness to investors. After conducting a detailed exploration, the probable reserve is defined with high accuracy and converted into proven reserve status. Since site selection is done considering the quality of lignite, it is assumed that a mine will be constructed and operated at the site to supply lignite to power plant, given that a demand for lignite fired power plant exists. The rate of lignite consumption is determined by the plant specifications and efficiency, and consumption will decrease the amount of proven reserves. Since mineral resources deplete with consumption, the chance of discovering new resources decreases, and cost of exploration increases with depletion. On the other hand, increasing consumption of lignite increases the price of the lignite and increasing the expected profit for investors. The loops observed in this system are negative feedback loops which tend to bring the system into a balance.

Based on the dynamics of system described above, the lignite supply module deals with and compares 17 lignite production regions, some of which are already brown fields and the remaining are green fields (reserves which are not previously mined). The regional classification is based on TKI and EUAS regional classifications and it is assumed that the lignite produced from a single field will carry similar chemical characteristics. Since the lignite reserves are evaluated regionally, the input supplied to the model is obtained by taking reserve weighted averages of chemical properties of each mine. The structure of lignite supply module for South Eastern Aegean Lignite Establishment (GELI- Güney Ege Linyitleri İşletmesi) is represented in

Figure 19. It should be noted that the same structure is constructed for 17 lignite production regions for comparison, coal quality being the major comparison factor for exploration and development investment decisions.

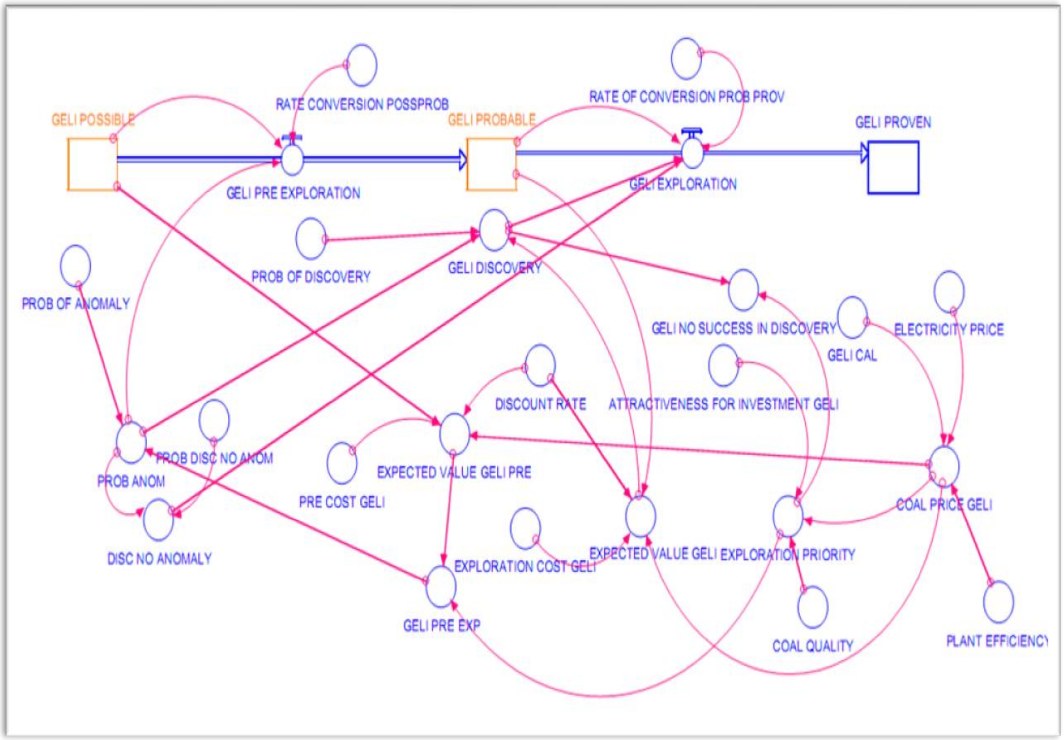


Figure 19. Lignite exploration and investment decision making in GELI

The main levels in the lignite exploration system are possible, probable and proven reserves denoted as GELI POSSIBLE, GELI PROBABLE and GELI PROVEN. The transition among these reserves is achieved by preliminary exploration and exploration activities, which are incorporated into the model as GELI PRE EXPLORATION and GELI EXPLORATION rates. Decision making to take exploration actions depends on three major factors, which are coal quality, attractiveness for investment and expected value of the reserve.

- Coal Quality

Coal quality variable ranks all available lignite reserves for further exploration priority by comparing all lignite prices calculated for each reserve, and selecting the lignite reserve with maximum price as the resource with highest quality. The assumption here is that the price of lignite reflects the chemical properties of lignite, through coal pricing equation developed by Elevli and Demirci(2003). Elevli and Demirci define hedonic pricing as a technique derived from multiple regression analysis relating quality parameters of non-homogeneous products with the prices of these products: In their study investigating the pricing of Turkish lignite reserves, they identified the most important physical parameter affecting lignite prices as, the lower boundary calorific value of coal and argued that the other properties such as ash and moisture values had low significance. Also, since the major end product of lignite is electricity, the regression analysis ran in the study has signified that, price of electricity and efficiency of the plant are other factors determining the price of the lignite, as derived in the following equation:

$$P_{lignite} = \left(\frac{\left(Cal_{lignite}\right)^2 * \eta}{86000} * P_{elec} * 0,36 \right) - 1,91 \qquad \text{(Equation 4)}$$

where

$P_{lignite}$ is the price of lignite

$Cal_{lignite}$ is the calorific value of lignite

η is the efficiency of the power plant

P_{elec} is the electricity price

The price calculations in the model use the calorific value of each reserve taken from government authorities. Electricity price in the base model is taken as 14¢$/kwh. Plant efficiencies are calculated by using the data from Thermal Power Plants in Turkey Report (2010), and in new capacity construction calculations, taken as 32%.

- Attractiveness for investment

This variable defines the favorability of legal framework for minerals development:

1-Favorable: The legal framework encourages mineral resources exploration and development.

0-Unfavorable: Mineral resources exploration and development is restricted by the legal framework.

- Exploration Priority

Exploration priority in each region determines to take the decision to explore: If coal quality equals coal price, in other words, the resource is selected as the one with highest quality, and attractiveness for investment is favorable, then the region is given exploration priority, and in the model, the value of this variable becomes 1.

- Expected value of the reserve

Net present value (NPV) of the expected value of the reserve is calculated twice in the model, for both taking preliminary exploration decision and exploration decision

Expected value of the reserve= NPV(Coal price* amount of expected discovery- Cost of exploration)

Discount rate is taken as 12% in NPV calculations.

- Preliminary exploration

If exploration priority equals to 1 and expected value of the reserve is greater than 0, preliminary exploration studies commence, and the value of the variable in the model equals to 1.

- Probability of Anomaly (PROB_ANOM), Probability of Discovery with No Anomaly Observed (PROB_DISC_NO_ANOM), Probability of Discovery (PROB_OF_DISCOVERY)

Probability of observing an anomaly/reserve discovery is estimated by running simple Monte Carlo simulations in the model. The probabilities used in the Monte Carlo simulations are taken from Guj (2008) which tries to estimate discovery probabilities of zinc reserves in Australia. It should be kept in mind that actual discovery rates are higher in case of lignite which is a more abundant mineral, however, due to the lack of a study analyzing discovery probabilities of lignite, the probability values for zinc reserve discoveries are assumed. These values are presented below:

1. Probability of observing an anomaly= 20.34%
2. Probability of observing no anomaly=79.66%
3. Probability of discovery given anomaly=4.79%
4. Probability of discovery given no anomaly=0.66%

- Observing an anomaly (PROB_ANOM), reserve discovery(GELI_DISCOVERY)

In the model, in order to determine if the exploration resulted in success or not, the above mentioned probabilities are used in Monte Carlo simulations observing an anomaly and discovering a new reserve. Monte Carlo simulations result in binary outcomes, 1 being positive exploration outcome and 0 being a failure. If the Monte Carlo simulation revealed success, resources are converted into reserves according to the level of accuracy, in line with commonly applied reserve classification systems, McKelvey Box, JORC, and SAMREC. According to these classification systems, possible, probable and proven resources are defined as:

Possible Resource: Tonnage, grade, and calorific value of the reserve can be estimated with a low level of confidence, based on the geological data obtained from trenches, pits, outcrops, drill holes.

Probable Resource: Level of confidence of the reserve is higher than that of possible resources, the amount and quality of the reserve is estimated using exploration data in hand, continuity of the reserve at this stage can be assumed however there are no guarantees of mineralization.

Proven Resource: Based on detailed and reliable exploration, sampling and testing, the resource can be defined with high level of confidence, while its geological continuity is now confirmed

- Rate of resource conversion (RATE_CONVERSION_POSSPROB, RATE_CONVERSION_POSSPROV)

In the model, if an anomaly and/or discovery is observed possible and probable reserves are converted into probable and proven reserves, respectively. The auxiliary variables RATE_CONVERSION_POSSPROB and RATE_CONVERSION_POSSPROV determine the amount of reserve converted into a higher significance level, based on the classification system significances.

- Determining success in exploration(GELI_NO_SUCCESS_IN_DISCOVERY)

Whether or not exploration study resulted in success is observed with this variable.

Once the lignite resources are converted into proven lignite reserves, the lignite reserve will be developed into an operating mine and lignite underground will be converted into lignite in stock to be consumed by the client.

4.2 Electricity Generation Sector

Electricity supply module aims to model the dynamics of electricity supply and demand in long-term by considering the electricity demand and price projections, relevant investment requirements.

4.2.1 Electricity Generation from Lignite Resources

The structure of electricity generation from lignite resources in the model is presented in Figure 20. Figure 20 above represents the outline of converting proven reserves into electricity by combustion in thermal power plants. The main levels in this sector are COAL_IN_STOCK,

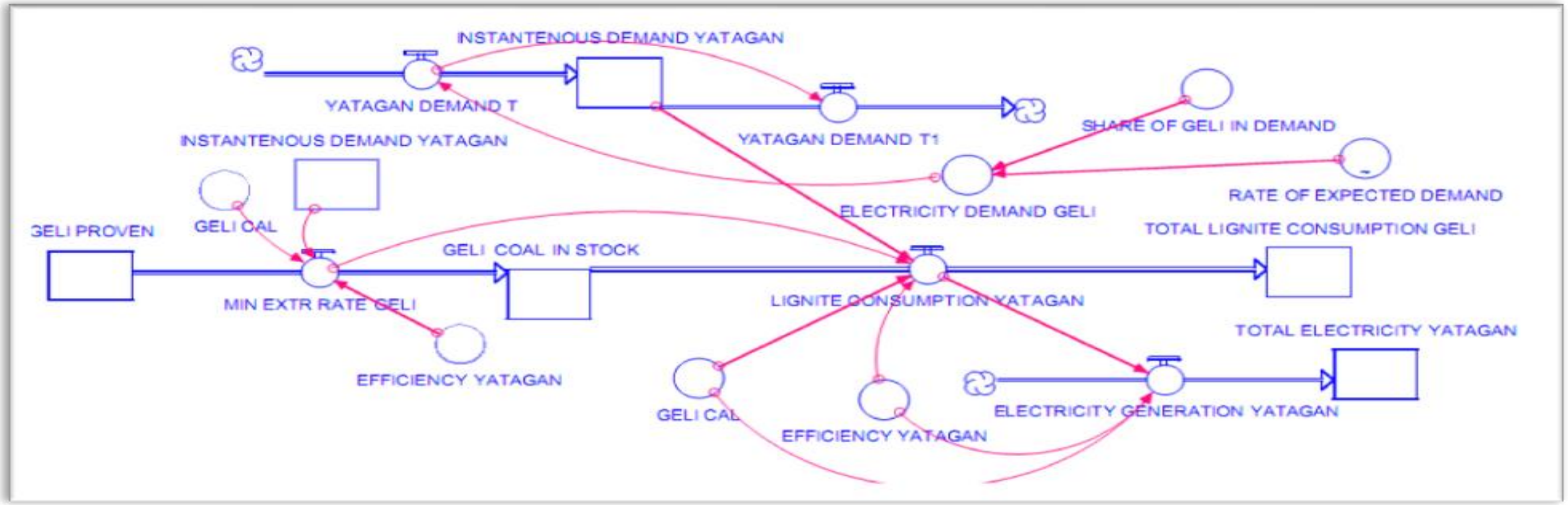


Figure 20. Electricity generation from proven reserves

TOTAL_LIGNITE_CONSUMPTION, TOTAL_ELECTRICITY_GENERATION and INSTANTANEOUS_DEMAND.

- Minimum Extraction Rate(MIN_EXTR_RATE_GELI)

Minimum extraction rate is the amount at which proven reserves are extracted to meet the demand from the power plant. Calorific value of the lignite at the specific region and plant efficiency are the main determinants of the amount to be extracted. Model checks the proven reserves before extraction so as not to extract an already depleted reserve.

- Coal in Stock (GALI_COAL_IN_STOCK)

Coal in stock is the amount of lignite stored in unit time, dt.

- Lignite Consumption (LIGNITE_CONSUMPTION_YATAGAN)

Lignite consumption at each region is calculated to meet the demand coming from the power plant. The inputs for this calculation are the total tons of lignite consumed, calorific value of the lignite, and efficiency of the plant. The model checks the existence of adequate lignite before consuming the lignite and converting it into electricity.

- Rate of electricity generation (ELECTRICITY_GENERATION_YATAGAN)

The lignite extracted is converted into electricity. 1 kwh electricity generated consumes 860 kcal of energy.

- Total Electricity (TOTAL_ELECTRICITY_YATAGAN)

The level accumulates the amount of total electricity generated in each year.

- Rate of Expected Demand

Rate of expected demand is estimated using the yearly peak demand expectations obtained from TEIAS(2004, 2009). The values of expected demand are distributed according to current share of primary energy resources in electricity generation.

- Share of Power Plant in Generation

Share of power plants in electricity generation are estimated with the aim of minimizing total cost of electricity generation. Electricity generation costs, which are to be minimized, ensuring that the electricity demand is met, are taken as the fixed cost of electricity generation. The cost of electricity generation in each plant is provided in Table 5. In the Table, fixed costs refer to the fixed portion of investment costs plus estimated operation and maintenance costs and variable costs are the costs of the plant due to fuel consumption.

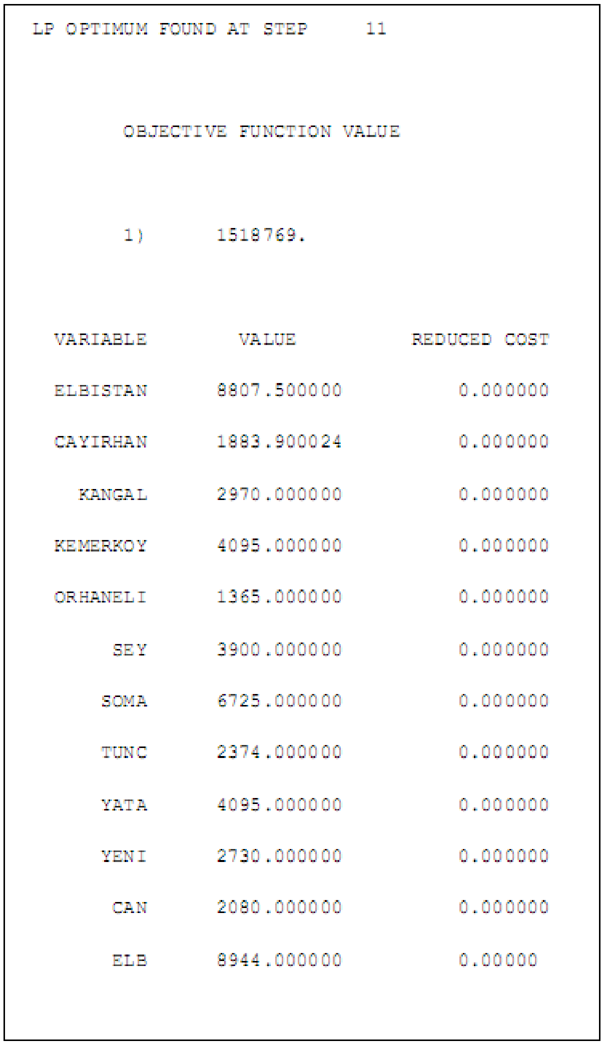
Table 5. Operation and maintenance costs of lignite fired power plants (TEIAS, 2004)

NAME OF THE PLANT	**OPERATION AND MAINTANENCE COST**		
	FIXED COST ($/Kw-month)	**FIXED COST ($/Kw-year)**	**VARIABLE COST ($/MWh)**
ELBİSTAN A 1-4	1.94	23.28	0.93
ÇAYIRHAN	4.77	57.24	4.11
KANGAL	3.46	41.52	0.99
KEMERKÖY	1.36	16.32	1.11
ORHANELİ	3.26	39.12	3.28
SEYİTÖMER	2.28	27.36	0.77
SOMA B	1.17	14.04	0.5
TUNÇBİLEK	3.63	43.56	1
YATAĞAN	2.92	35.04	0.88
YENİKÖY	2.57	30.84	0.69
CAN	3	36	1
ELBİSTAN B	3.31	39.72	5.06

In order to optimize the cost of electricity generation from lignite fired power plants and to determine the amount of capacity utilization in each plant, a linear programming problem, which minimizes total cost of electricity generation in lignite fired power plants, is formulated. The costs used in the minimization problem are taken as the fixed costs of yearly generation since variable costs depend on the amount of capacity utilization. The following linear programming model is prepared and solved in Lingo 10.0

```
“MIN
23.28ELBISTAN+57.24CAYIRHAN+41.52KANGAL+16.32KEMERKOY+39.12ORHANELI+27.36SEY+14.04SOMA+43.56TUNC+35.04YATA+30.84YENI+36CAN+39.72ELB
ST
ELBISTAN<=2203.5
CAYIRHAN<=4030
KANGAL<=2964
KEMERKOY<=4095
ORHANELI<=1365
SEY<=3900
SOMA<=6708
TUNC<=2379
YATA<=4095
YENI<=2730
CAN<=2080
ELB<=8944
ELBISTAN+CAYIRHAN+KANGAL+KEMERKOY+ORHANELI+SEY+SOMA+TUNC+YATA+YENI+CAN+ELB>=44088.19344
END”
```

The model output provides the optimum capacity utilization in each power plant while meeting electricity demand for lignite fired plants (Figure 21):



```
LP OPTIMUM FOUND AT STEP     11


        OBJECTIVE FUNCTION VALUE


        1)       1518769.


  VARIABLE         VALUE           REDUCED COST

  ELBISTAN      8807.500000          0.000000

  CAYIRHAN      1883.900024          0.000000

    KANGAL      2970.000000          0.000000

  KEMERKOY      4095.000000          0.000000

  ORHANELI      1365.000000          0.000000

       SEY      3900.000000          0.000000

      SOMA      6725.000000          0.000000

      TUNC      2374.000000          0.000000

      YATA      4095.000000          0.000000

      YENI      2730.000000          0.000000

       CAN      2080.000000          0.000000

       ELB      8944.000000          0.00000
```

Figure 21. Lingo output

The model solution have shown that the capacity utilization values above minimize total fixed cost of electricity generation at 1.518.769 USD/kw-year.

Accordingly, the shares of lignite fired power plants in the model are calculated by taking the ratio of the capacity utilization of the power plant to overall lignite fired thermal capacity utilization demand. In this regard, the optimal share of existing power plants in electricity generation are presented in Table 6.

Table 6. Share of differrent power plants in lignite fired electricity generation.

NAME OF THE PLANT	**% SHARE IN GENERATION**
ELBISTAN 1-4	17,63
ÇAYIRHAN	3,77
KANGAL	5,94
KEMERKOY	8,20
ORHANELI	2,73
SEYITOMER	7,80
SOMA	13,46
TUNÇBILEK	4,75
YATAĞAN	8,20
YENİKÖY	5,46
ÇAN	4,16
ELBİSTAN	17,90
TOTAL	**100,00**

- Instantaneous Demand

Instantaneous demand is a dummy variable for distributing demand to mining companies, and the value of each year's electricity demand from specific mine establishment is stored in this variable: The plant demand at time t+1 introduced by a delay of one year equals plant demand at time t, and therefore the information on yearly demand is transmitted to rate of lignite consumption.

4.2.2 Electricity Supply

Electricity supply security in the long term depends on generation capacity investments and aging of the capacity. Firms invest when firms expect supernatural profits, and in the same sense investment rate decelerates when they expect subnormal profits (Figure 22). Inaccurate estimates of electricity demand (and therefore price) and neglecting delays in commissioning of plants due to permit and construction issues, cause boom and busts cycles in electricity industry (Ford, 1999).

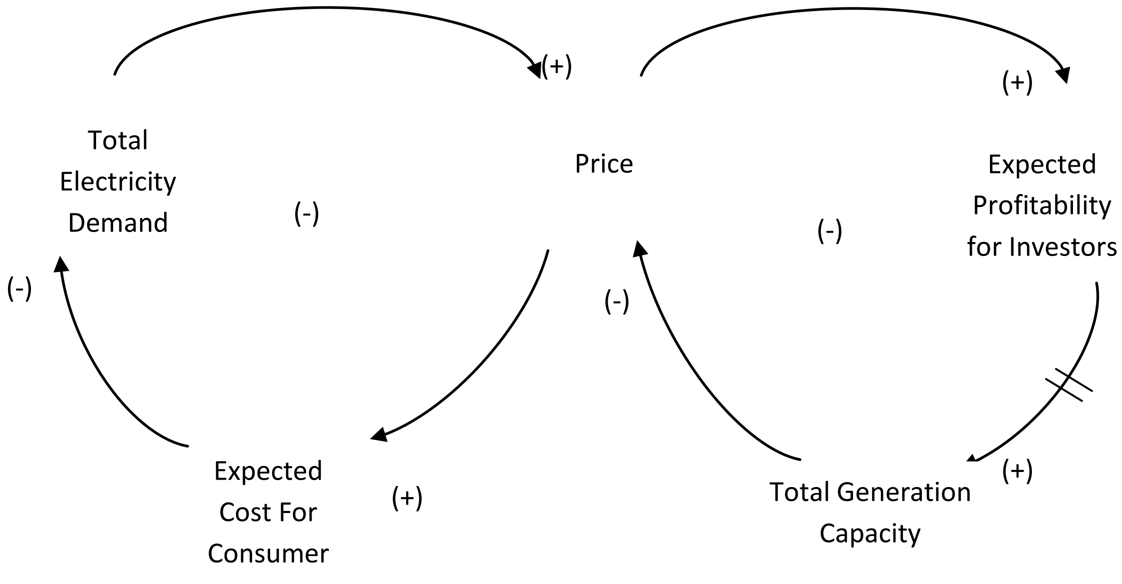


Figure 22. Investment cycle in electricity sector

The investment cycle above is adapted to electricity investment sector in detail to define the most suitable type of investment to meet total electricity demand Figure 23.

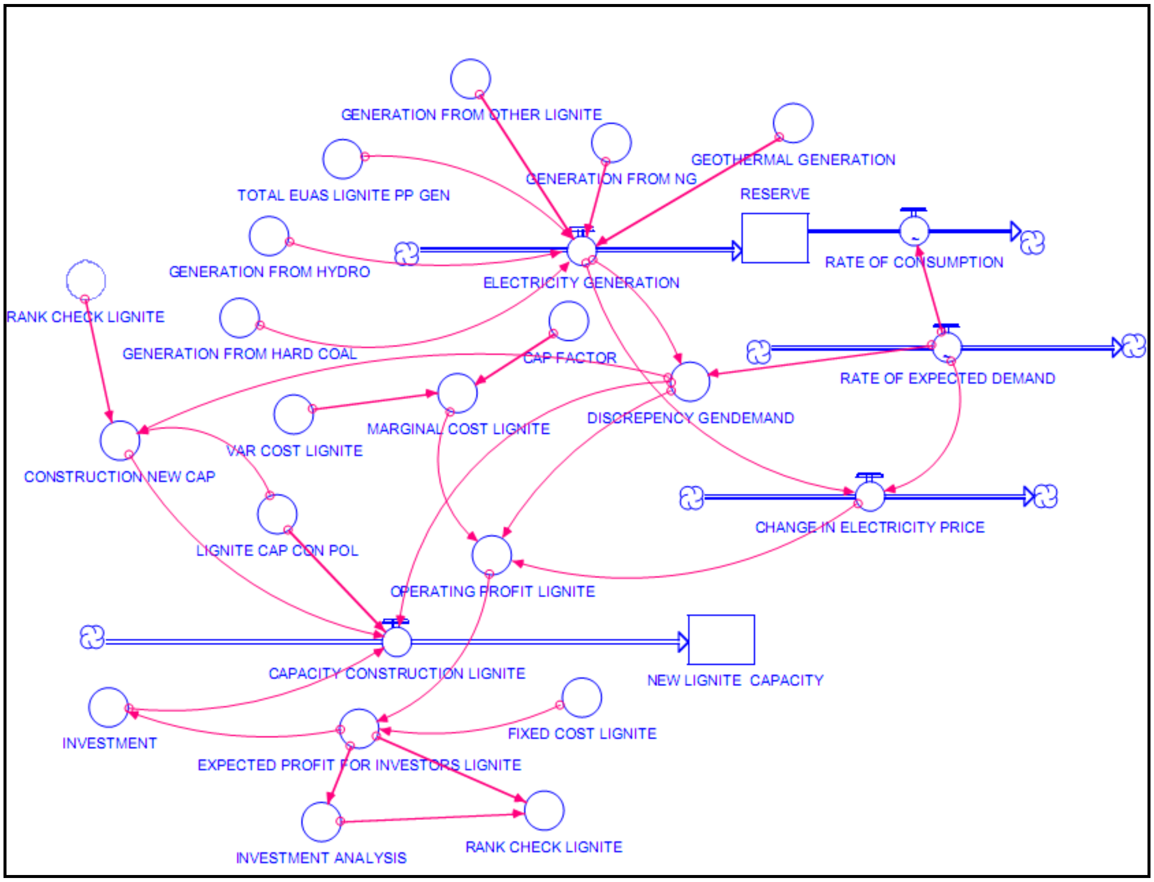


Figure 23.Investment in new generation capacities to meet the electricity demand.

The Figure above summarizes the dynamics of investing in new generation capacities. It should be noted that, while the variables electricity generation-consumption, expected demand, investment analysis and electricity price are common in calculation, capacity construction for each fuel type is investigated separately.

- Electricity generation

Electricity generation is the sum of all electricity generation coming from all types of fuels (EUAS lignite electricity generation, other lignite fired power plants, natural gas fired power plants, hard coal plants, hydraulic generation, wind plants, solar plants, geothermal plants). While EUAS power plants are investigated in detail in terms of reserves, other fuel types are contributing to the generation according to their installed capacities. All capacities are degregating at a rate of 0.96% each year, and thus, total generation declines unless new capacity additions are not built.

- Rate of expected electricity demand

Rate of expected electricity demand equals to official data provided by TEIAŞ Electricity generation from existing power plants and new power plant investments are based on electricity demand forecasts. Expected peak demand values are taken from official capacity prediction study of Turkish Electricity Transmission Company(TEIAS, 2004,2009). In these studies TEIAS assumes two scenario's for projecting electricity demand: In the base scenario expected value of GDP increases 5.5% between 2010-2030 and in the low demand scenario, the increase in GDP is 4.5% in the same period(Table 7,Table 8)

Table 7. Expected Demand in Base Scenario (TEIAS, 2004, 2009)

YEAR	**PEAK DEMAND**		**ELECTRICITY DEMAND**	
	MW	**% Increase**	**(GWh)**	**% Increase**
2010	31.245,50	4,50%	202.730,00	4,50%
2011	33.276,46	6,50%	215.907,45	6,50%
2012	35.772,19	7,50%	232.100,51	7,50%
2013	38.455,11	7,50%	249.508,05	7,50%
2014	41.339,24	7,50%	268.221,15	7,50%

Table 7. Expected Demand in Base Scenario (TEIAS, 2004, 2009) (Cont'd).

YEAR	PEAK DEMAND		ELECTRICITY DEMAND	
	MW	% Increase	(GWh)	% Increase
2016	47.728,22	7,40%	309.674,73	7,40%
2017	51.260,11	7,40%	332.590,66	7,40%
2018	55.053,35	7,40%	357.202,37	7,40%
2019	58.796,98	6,80%	381.492,13	6,80%
2020	62.559,99	6,40%	405.907,63	6,40%

Table 8. Expected Demand in Low Demand Scenario (TEIAS, 2004, 2009)

YEAR	PEAK DEMAND		ELECTRICITY DEMAND	
	MW	% Increase	(GWh)	% Increase
2009	29.900,00		194.000,00	
2010	31.245,50	4,50%	202.730,00	4,50%
2011	32.964,00	5,50%	213.880,15	5,50%
2012	35.172,59	6,70%	228.210,12	6,70%
2013	37.810,53	7,50%	245.325,88	7,50%
2014	40.646,33	7,50%	263.725,32	7,50%
2015	43.694,80	7,50%	283.504,72	7,50%
2016	46.578,66	6,60%	302.216,03	6,60%
2017	49.652,85	6,60%	322.162,29	6,60%
2018	52.929,94	6,60%	343.425,00	6,60%
2019	56.529,17	6,80%	366.777,90	6,80%
2020	60.147,04	6,40%	390.251,69	6,40%

The rate of expected demand uses the demand expectations of high demand scenario in gWh.

- Discrepancy between electricity generation and demand

This variable calculates the difference between electricity supply and electricity demand. If electricity demand is greater than electricity supply, the difference is tried to be reduced by introducing new capacities with a construction delay period.

- Change in price

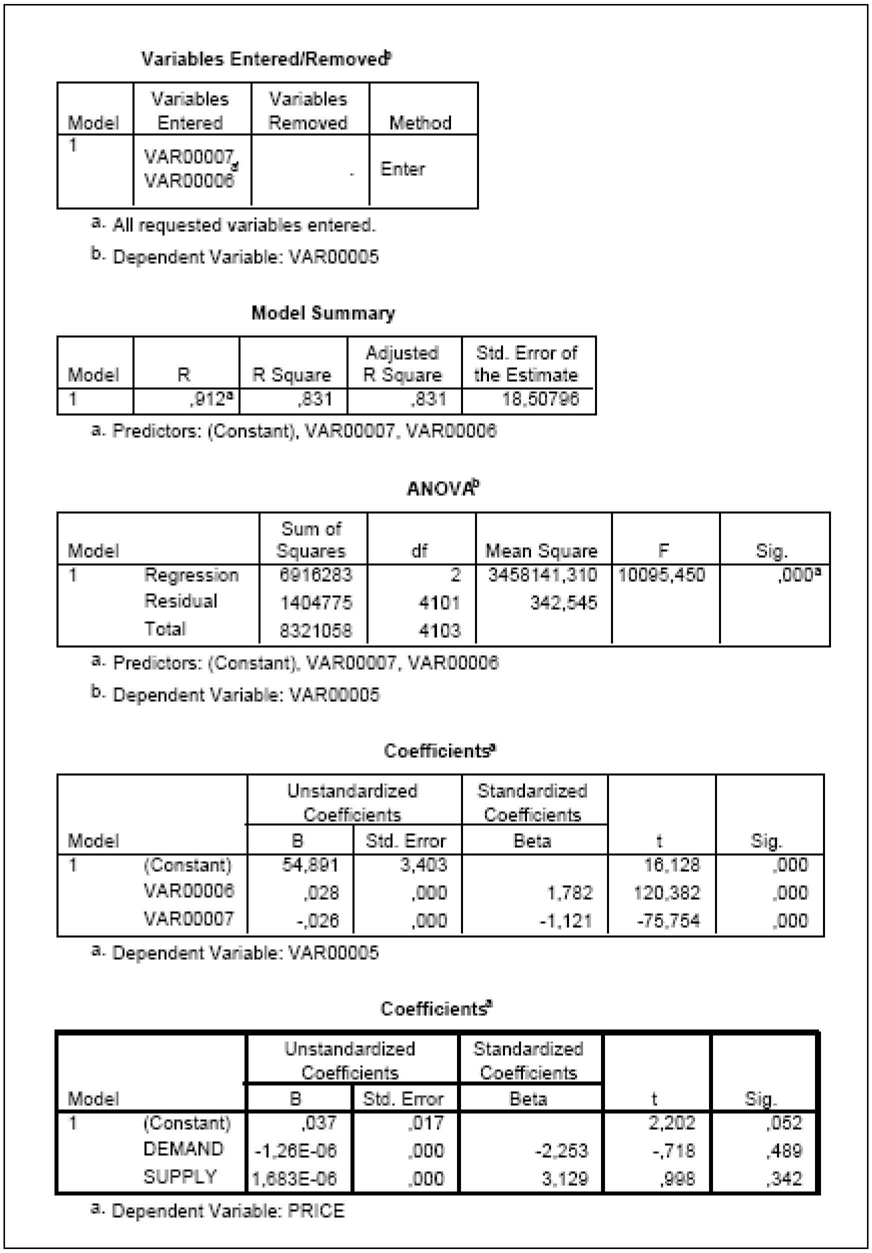
In order to determine the electricity price, spot electricity price, electricity consumption and electricity generation data in years 2009-2010 are analyzed in SPSS 15.0. The result of linear regression is presented in Figure 24.

Based on the results of regression analysis below, change in price variable in the system dynamics model uses the following equation to compute the market price:

Price= (54.891+Rate_Of_Expected_Demand*0.028-0.026*Electricity_Generation) (Equation 3)

It should be noted that actual electricity price estimations consider a variety of other factors including seasonality, exchange rates, fuel prices, etc, due to lack of adequate and accurate data, this study is based on electricity supply, demand and spot prices formed in the market.

When determining the type of plants to invest in, the fluctuations of demand should be considered and investment should be planned so as to meet the peak demand. General characteristics of plants meeting base and peak loads are compared in Table 9 given below.



Variables Entered/Removed[b]

Model	Variables Entered	Variables Removed	Method
1	VAR00007, VAR00006[a]	.	Enter

[a] All requested variables entered.

[b] Dependent Variable: VAR00005

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	,912[a]	,831	,831	18,50796

a. Predictors: (Constant), VAR00007, VAR00006

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	6916283	2	3458141,310	10095,450	,000[a]
	Residual	1404775	4101	342,545		
	Total	8321058	4103			

[a] Predictors: (Constant), VAR00007, VAR00006

[b] Dependent Variable: VAR00005

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	54,891	3,403		16,128	,000
	VAR00006	,028	,000	1,782	120,382	,000
	VAR00007	-,026	,000	-1,121	-75,754	,000

[a] Dependent Variable: VAR00005

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	,037	,017		2,202	,052
	DEMAND	-1,26E-06	,000	-2,253	-,718	,489
	SUPPLY	1,683E-06	,000	3,129	,998	,342

[a] Dependent Variable: PRICE

Figure 24. Results of regression model

Table 9. Comparison of base-load plants and peak load plants (Olsina et al.,2006)

Base Load Capacity	**Peak Load Capacity**
Long permitting procedures	Short-notice, no long permit process
High investment costs therefore require well-established firms	Small and inexperienced firms can undertake these investments.
Usually no significant over-capacity generated	Generation behavior due to following market trends
Longer investment period	Lower capital costs and shorter investment period

- Fixed Cost

Fixed costs reflect the investment per unit capacity.

- Variable costs

Variable costs, which are the portion of costs that change with electricity generation in a given period. In power plants, variable costs are usually directly influenced by the fuel costs. Olsina et al (2006) define the average hourly fixed and variable costs as follows respectively:

Hourly Fixed Cost (FC)= $\frac{\rho \cdot IC}{1 - e^{-\rho \mathrm{T}_a}} \cdot \frac{1}{8760}$ (€/MWh) (Equation 5)

Where ρ is the discount rate

IC is the investment cost of the plant

Ta is the amortization period or life time of the plant

Variable Costs (VC)= $C_i.P_{fuel}.E_i$ =MCi. Pmax. Ti ^{F}(€/yr) (Equation 6)

where

C_i =Average fuel consumption of the generator (GJ/MWh)

P_{fuel}= Price of fuel (€/GJ)

E_i =Annual energy produced(MWh/yr)

MCi is the marginal cost of electricity generation (€/MWh)

Pmax is the maximum output of the generator (MW)

Ti^F is generators full load hours(hr/yr)

If Equation 2 is divided by Pmax and total number of hours in a year (1 yr=8760 hours), hourly variable cost becomes:

$$VCi=\frac{MCi.Ti^{F}}{8760}= MCi.D \text{ (€/MWh)} \qquad \text{(Equation 7)}$$

Where D is the capacity factor of the technology

Finally, total cost of generation becomes:

C_{Ti}= FCi+VCi=FCi+MCi. D (€/MWh) (Olsina, Garces, & Haubrich, 2006) (Equation 8)

- Investment Cost

In order to calculate the investment costs in the model, the data from IEA report "Projected Costs of Generating Energy, 2005 Update" (IEA/OECD, 2005) is used, and electricity generation investment and construction duration is summarized in Table 10.

The model then calculates the hourly generation cost for each capacity at the amount of discrepancy by using the investment costs (Table 10) and equations (Equations 5-8) described above (Figure 25).

Table 10. Cost of power plant investment and average construction period

Type of Plant According to Fuel Consumption	Overnight Cost	Construction Period
Lignite Fired Generation	1000-1500(USD/kWe)	4 years
Natural Gas Fired Generation	400-800(USD/kWe)	2-3 years
Nuclear Generation	1000-2000 (USD/kWe)	5 -10 years
Wind Generation Technologies	1000-2000(USD/kWe)	1-2 years
Hydro Generation	1000-7000 (USD/kWe)*	3 years
Solar Generation	2775-10164 (USD/kWe)	1 year
Geothermal Generation	1500-2500 (USD/kWe)	1-3 years

*Generation costs vary due to differences in site characteristics

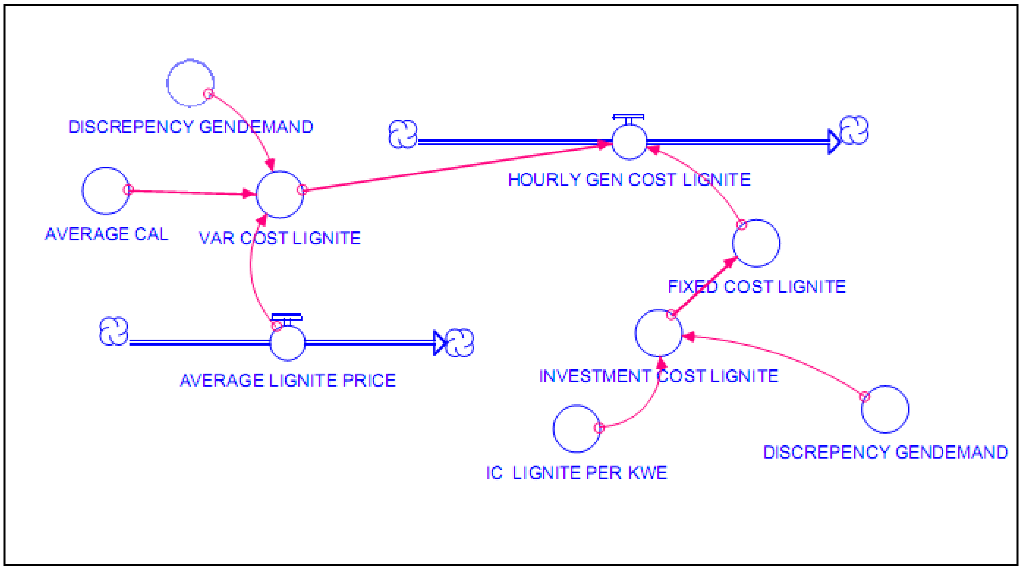


Figure 25. Cost of electricity generation

- Expected profit for investors

In competitive markets investment decisions are directly affected by the expected profitability of the investment. As mentioned before, the electricity generation capacity and efficiency declines with the aging of the plants, and if not invested in new capacity, the gap between capacity and demand may lead to power shortages, which in return would have direct impacts on economic output.

The investment decision making loop used in this study in lignite fired power plant is given in Figure 26. Total lignite fired capacity is increased by expected profitability of capacity investment in lignite fired power plants and decreased by the retirement of aged capacity. Reserve is the available power capacity at time t, which is also influenced positively by other electricity generation capacities using different type of fuels, decreases with electricity demand. Available reserve decreases the spot market electricity prices. Since the investors tend to decide on investments based on the previous behavior of the electricity market, long term price expectations increase the long term prices, which increase the expected profitability for investors. Also, as mentioned before, the fuel prices have direct influence on the marginal cost of electricity generation, thus expected profitability of investment is also influenced by expected lignite prices. Finally, total lignite fired capacity increases by the construction of the new plant with a delay depending on the permit and construction processes.

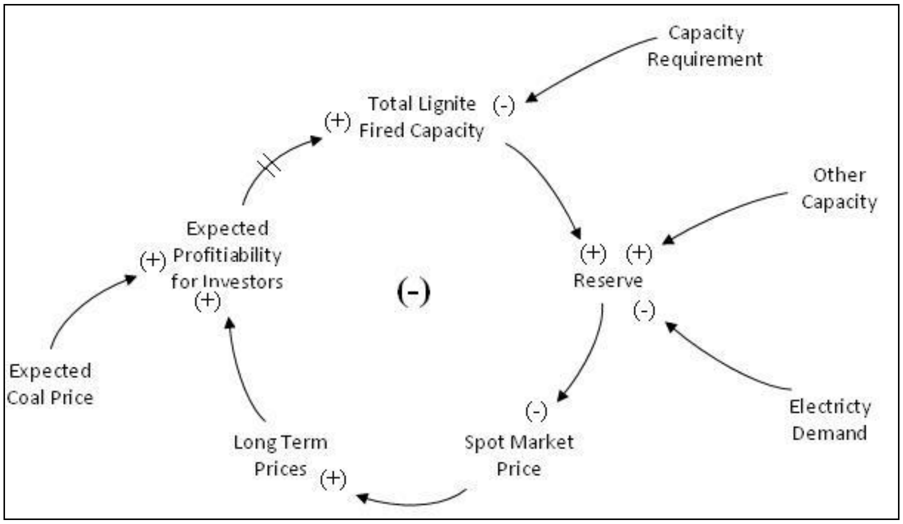


Figure 26. Dynamics of investment in lignite fired power plant (adapted from Olsina et al, 2007)

- Operating profit

The operating profit from investing in a power plant can then be mathematically expressed as:

$$\pi(t) = q\int_{to}^{to+ta} e^{-\rho t}(P(t) - MC(t)dt \qquad \text{(Equation 9)}$$

Where

π is the expected operating profit at time t

t_o is the period of time delay due to construction and permit processes

ta is the life of the plant

q is the availability of capacity

ρ is the discount rate

P(t) is the price at time t

MC(t) is the marginal cost of generation at time t

The hourly average expected profit then becomes:

$$\Pi(t) = \frac{\pi(t)(1+\rho)^{-ti}}{8760} - FCi \qquad \text{(Equation 10)}$$

where

Π is the operating profit at time t

ρ is the discount rate,

FC_i is the fixed cost of capacity investment

- Capacity control policy (LIGNITE_CAP_CON_POL)

This variable reflects the choices of policy maker, ie. determines whether to invest in a certain policy, if the value is 1, the decision is to invest in the capacity, if value is zero, decision-maker chooses not to invest in certain type of capacity.

- Investment

Checks if the expected profit for investors is greater than 0 or not.

- Investment analysis

Investment analysis check determines the capacity that provides maximum profit to the investors by ranking expected profits for all fuel types.

- Rank check

Rank check controls if expected profit for investors equals to investment analysis.

- Construction new capacity

Construction new capacity is the average construction time for specific generation type.

- Capacity construction

Capacity construction rate determines whether to construct required capacity at a time delay of construction new capacity, using a specific fuel type by comparing investment analysis and expected profit for investors (if these variables are equal, than that certain fuel type is the one with the most profit), investment (If equals to 1, then this investment is profitable) and capacity control policy (if equals to 1, the policy of the decision maker is to construct the facility).

4.2.3 Electricity generation from other resources

Generation from other resources are restricted to established and new capacities of fuel types. Figure 27 represents the general structure for electricity generation. For all energy resources, electricity generation from that resource is restricted to available maximum capacity of that resource, and installed capacity equals to capacity values officially provided by the government. Capacity construction adds to installed capacity, and installed capacity is turned into electricity generation at the capacity factor for that resource.

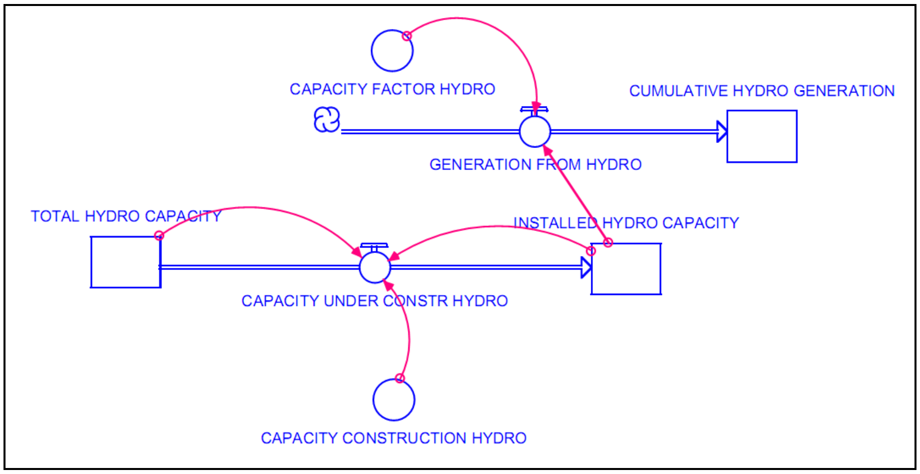


Figure 27. Electricity generation from hydro energy resources

4.2.4 Emission Calculations In Lignite Fired Power Plants

There are various methodologies to calculate the emissions generated from lignite fired power plants, however the accuracy of available data restricts the utilization of these methodologies. Therefore, in this study, a more generalized emissions prediction, derived by Intergovermental Panel for Climate Change (IPCC) is used for estimation of emissions. According to IPCC (1996), total carbon emissions are calculated as follows:

$$TCO_2 = FC*CC*CEF*OCR*CO_2/C \qquad \text{(Equation 11)}$$

where

TCO_2 is the total tons of CO_2 generation

FC is the fuel consumption in tons of oil equivalent (toe)

CC is the conversion coefficient and equals 41.868 TJ/ toe

CEF is the carbon emissions factor(tC/TJ), 27.6 for lignite

OCR is the oxidized carbon ratio, equals to 0.980 for lignite

CO2/C is the ratio of the molecular weight of carbondioxide to atomic weight of carbon

The emissions sector in the model uses lignite consumption in each plant as input in Equation 6 to calculate the amount of CO2 emitted by these plants. Emissions from other energy resources are also calculated in the same way, however the CEF and OCR values are modified according to the fuel type as presented in Table 11.

Table 11. CEF and OCR values for fuels

Fuel	Carbon Emission Factor (CEF)	Oxidized Carbon Ratio (OCR)
Hard Coal	25.8	0.980
Lignite	27.6	0.980

Table 11. CEF and OCR values for fuels (cont'd.)

Fuel	**Carbon Emission Factor (CEF)**	**Oxidized Carbon Ratio (OCR)**
LPG	17.2	0.995
Jet Fuel	19.5	0.990
Fuel Oil	20.2	0.990
Oil	20.0	0.995
Natural Gas	15.3	0.995
Other oil products	20.2	0.990

Accordingly, CO2 emissions from each plant are calculated as shown in Figure 28:

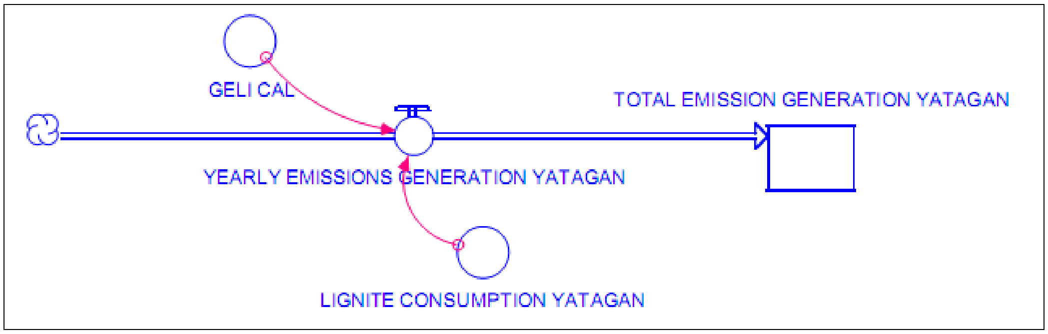


Figure 28.Emissions generation from a single plant

The model calculates yearly emissions generation (tons) as: Tons of lignite (t)*1000(kg/t) *cal value of lignite (kcal/kg)*0.0000001(toe/kcal)*41.868(TJ/toe)*27.6(Tc/TJ)*0.980*3.667

CHAPTER 5

SUSTAINABILITY OF TURKISH LIGNITE RESERVES UNDER DIFFERENT SCENARIOS

5.1 Base Scenario

The aim of base scenario is to check the models ability to regenerate current electricity generation values of the established capacity in Turkey, and to analyze required capacity additions, as well as investigating the depletion rate of lignite reserves if all new capacity were to be constructed as lignite fired capacities at green field reserves. For this purpose, amount of electricity generation of lignite fired power plants in 2008 are defined as inputs to the model, to observe if the model is capable of extract required amount of lignite. For other electricity generation capacities, expected rate of demand is defined as input. Although different plants have different capacity factors, which in return affect their total generation, these values are assumed to be constant at 74,2%, for this value is also used in official documents. In this regard, in order to explain the model algorithm, firstly the ability of the model to regenerate lignite extraction and reserve depletion at 2008 electricity demands is simulated at an arbitrary plant (Kemerköy), next, the results lignite price calculation, selection of appropriate reserve among different reserves is explained. Although all reserves in the model (except for greenfield reserves) are exploited continuously, since model identifies Çan reserves as the appropriate reserve for exploration, the exploitation of reserves, relevant electricity generation from power plant, degradation of plant capacity are clarified for Çan plant.

Total electricity generation and demand are also simulated in the model to determine the amount of deficit/surplus of electricity. Electricity prices are tried to be estimated based on supply and demand, which in turn affects both lignite prices and the profitability of different investment. It is assumed that, the electricity deficit will be tried to be met by domestic generation (no imports or exports) and under this assumption, supply of electricity does not get affected from price: Electricity deficit determines the amount of required new capacity at year t, and investors, based on the electricity prices and both variable and investment costs at year t, determine the most profitable resource for electricity generation, which turns out to be lignite in base scenario. At the next step, another assumption of the model is that currently generating lignite fields will not be considered for plant construction but green fields will be exploited. Since the required additional capacity is too high, proven reserves at these fields deplete almost simultaneously, leading to the conclusion that, electricity generation resources must be diversified. Finally, increase in emissions generation due to lignite consumption is simulated. The details of base run are given below.

5.1.1 Lignite consumption

Lignite fired plants forecast electricity generation amounts according to forecasted electricity demand. In a similar manner, lignite production from mines are planned so as to meet the electricity generation requirement of each plant.

In order to compare actual lignite consumption in each plant with lignite consumption value generated by the model, actual electricity demand coming to each plant is used as the input to check whether the model produces actual amount of lignite.

Although there are twelve lignite-fired power plants in the model, since the algorithm for lignite production are the similar in each plant and reserve, the results for only one power plant, which is selected arbitrarily, is discussed: According to Thermal Power Plants in Turkey Report (2009), in 2008, yearly electricity generation of Kemerköy power plant occurred as 3.410.550.000 kWh. The calorific value of the lignite was 1801 kcal/kg and total lignite consumption was 4.926.130 tons.

The inputs to the model are therefore as follows:

Electricity demand: 3.410.550.000 kWh

Calorific value:1951 kcal/kg

Given the electricity demand as input, the model consumes 4.525.357,28 tons of lignite to generate the required amount of electricity (Figure 29). The difference between actual (4.926.130 tons)and simulated consumption is mainly due to the difference in calorific value of lignite, as the model uses average lignite calorific value from EUAS data.

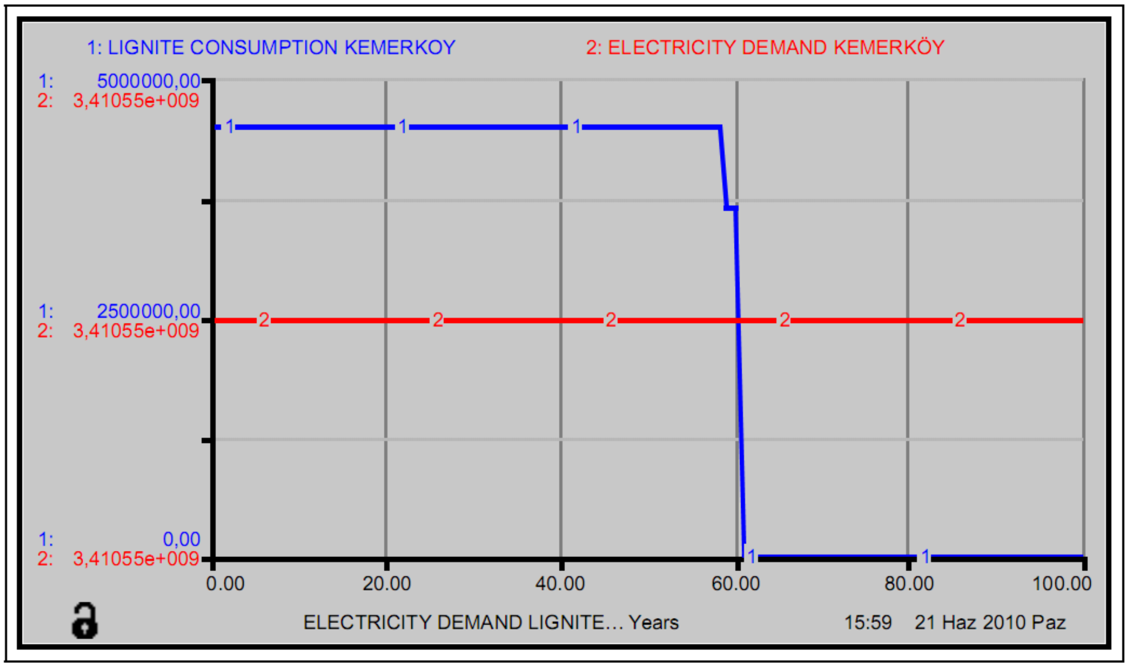


Figure 29. Lignite consumption at Kemerköy power plant to meet the required electricity demand

At this lignite consumption rate, the reserves supplying Kemerköy power plant will be depleting in 60 years, unless the area is explored and further reserves are discovered, as shown in Figure 30.

5.1.2 *Lignite supply*

Exploration and discovery for discovering reserves are restricted to known areas. In this regard, the lignite reserve with highest quality, defined as the lignite with highest price, will be selected as the area to further exploration. Lignite prices normally fluctuate due to changing electricity prices and might also vary with thermal efficiency of the power plant constructed, however, in the base simulation, the electricity price is set constant to 7 $¢/kwh.

The lignite prices of the reserves are given in Table 12. The coal quality variable then compares all prices (except Silopi and Şırnak) to determine the prioritized resource for additional exploration (Figure 31) and chooses Çan lignites to be the best quality lignite, based on the available calorific values at a price of 47 $/ton. The region is also set as an attractive region for exploration, therefore attractiveness for investment equals to 0.

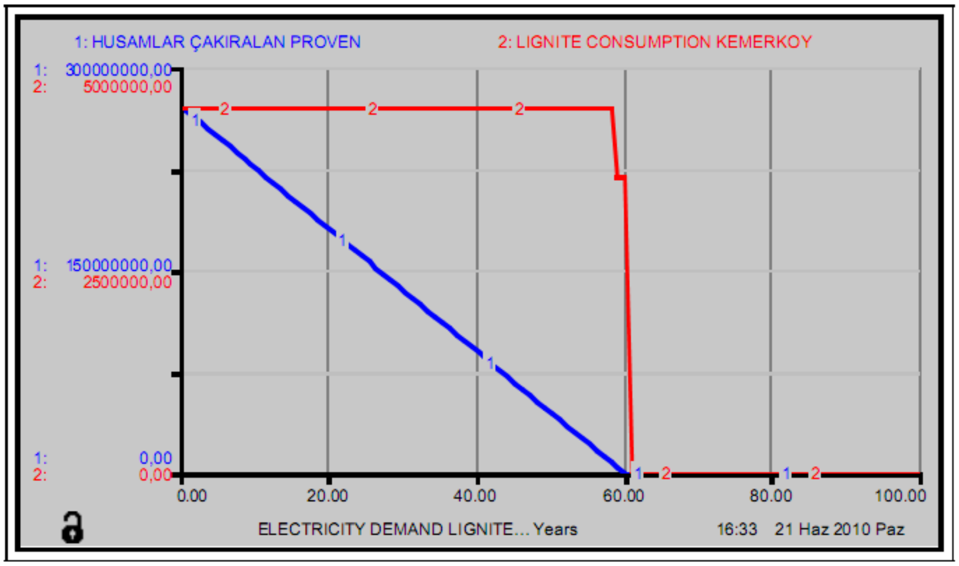
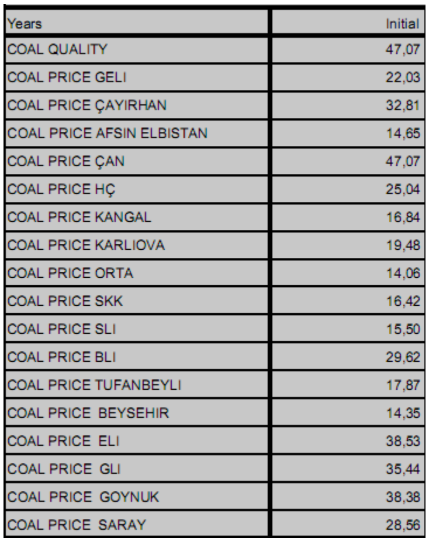


Figure 30. Electricity Demand and Proven Reserve

Table 12. Lignite prices at different reserves based on electricity price and plant efficiencies ($/ton)



Years	Initial
COAL QUALITY	47,07
COAL PRICE GELI	22,03
COAL PRICE ÇAYIRHAN	32,81
COAL PRICE AFSIN ELBISTAN	14,65
COAL PRICE ÇAN	47,07
COAL PRICE HÇ	25,04
COAL PRICE KANGAL	16,84
COAL PRICE KARLIOVA	19,48
COAL PRICE ORTA	14,06
COAL PRICE SKK	16,42
COAL PRICE SLI	15,50
COAL PRICE BLI	29,62
COAL PRICE TUFANBEYLI	17,87
COAL PRICE BEYSEHIR	14,35
COAL PRICE ELI	38,53
COAL PRICE GLI	35,44
COAL PRICE GOYNUK	38,38
COAL PRICE SARAY	28,56

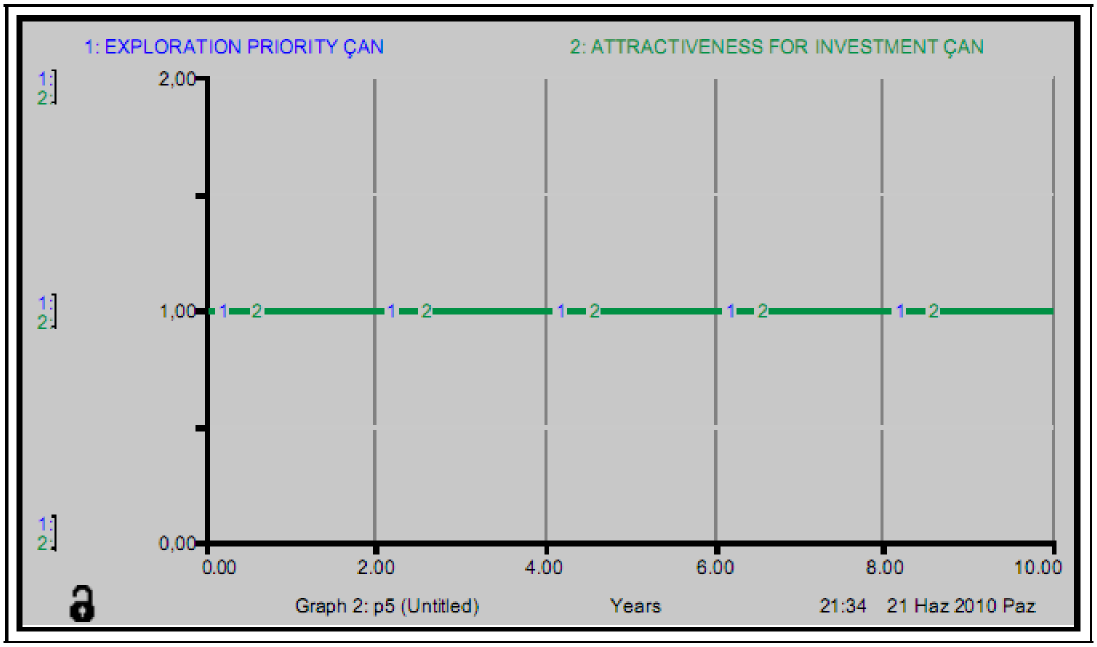


Figure 31. Exploration priority and attractiveness for investment

Given exploration priority as 1 in Çan lignites, the model tries to evaluate the chance of discovering new reserves in the area by conducting a Monte Carlo simulation with probabilities defined in Chapter 4. The result of the simulation in Çan is given in Figure 32 below: When Monte Carlo simulation results in discovery in year 0, the value of probability of anomaly becomes 1, and after a pre exploration period of 3 years, 40% of possible resources are converted into probable reserves. Preliminary exploration commences with observing an anomaly. It should be noted that the probability values used in the model are originally developed for metallic minerals and despite pretty frequent discoveries are observed in Çan lignites, at other locations, there might be no discoveries at all (Figure 33)

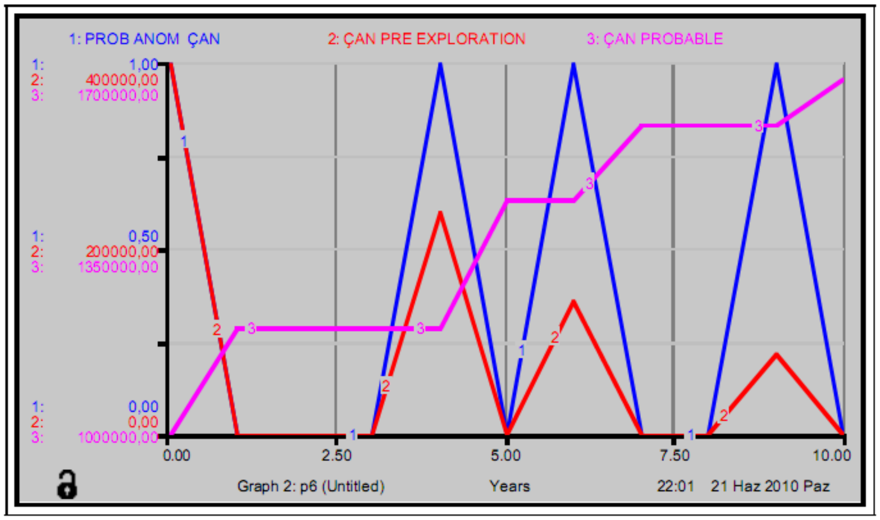


Figure 32 Probability of anomaly, rate of preliminary exploration and probable reserve in Çan

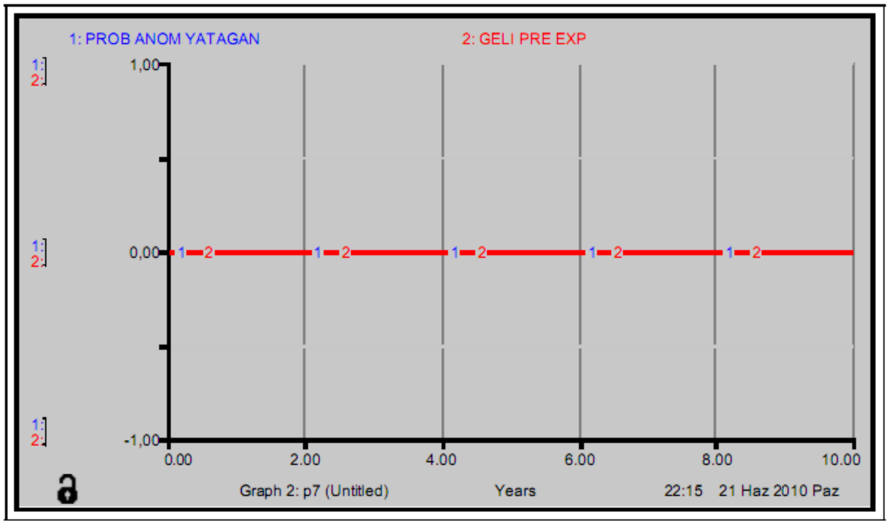


Figure 33. Failed preliminary exploration in Yatağan

Once preliminary exploration results in success as in the case for Çan lignites, it is assumed that a more intensive exploration programme is conducted, with a prior probability of discovery. Success in this exploration is determined by Monte Carlo simulation. Figure 34 shows the discovery at time 0, leading to a small increase in Çan proven reserves, which is simultaneously being consumed by the existing 320 MWe Plant. While discovering additional reserves, the model also takes into account the probability of discovering new reserves with no findings during pre-eliminary exploration.

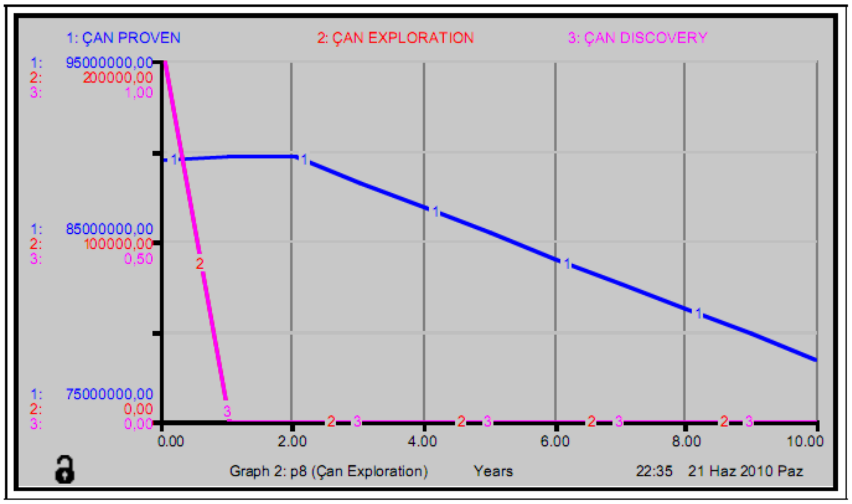


Figure 34. Exploration and discovery in Çan

5.1.3 Electricity Generation from Lignite Fired Power Plant

As mentioned above, electricity generation is determined according to yearly electricity demand to be generated by lignite fired power plants. The electricity demand for next 10 years is forecasted by TEIAS, and the model uses these values to generate electricity (Figure 35). and to consume lignite (Figure 36). In Figure 35, total electricity demand is in gWh whereas electricity demand and generation from Çan are in kwh. In both Figures, slight declines in electricity demand, generation and lignite consumption can be observed due to plant capacity degradation (Figure 37).

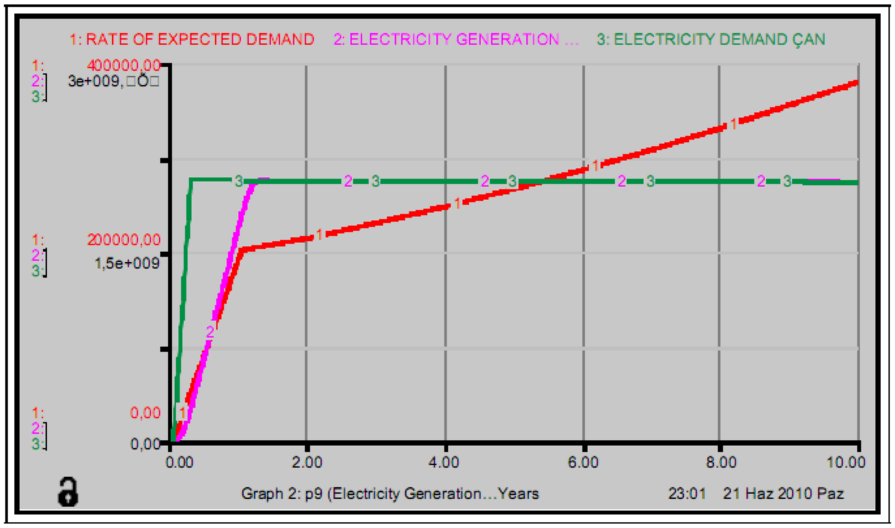


Figure 35. Rate of expected demand, electricity demand from Çan, electricity generation by Çan(kwh).

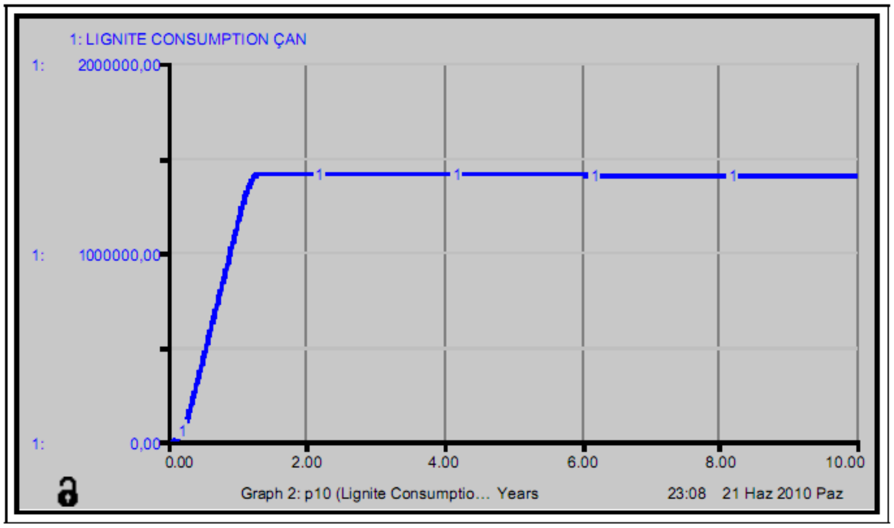


Figure 36. Lignite consumption in Çan (tons)

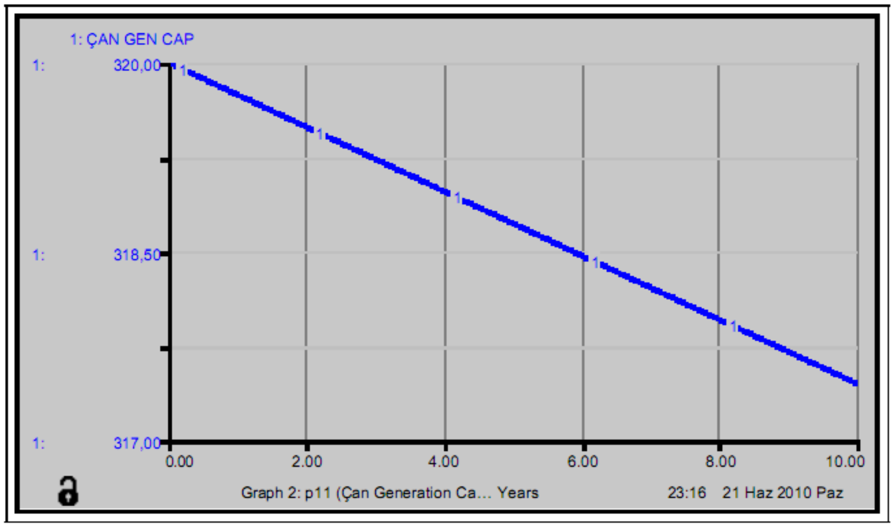


Figure 37. Decline in generation capacity of Çan power plant (MWe)

5.1.4 Emissions Generation from Single Plant

CO2 emissions produced by electricity generation in each plant are calculated using the methodology described in Chapter 4. The model output showing CO2 generation from Çan is presented in Figure 38.

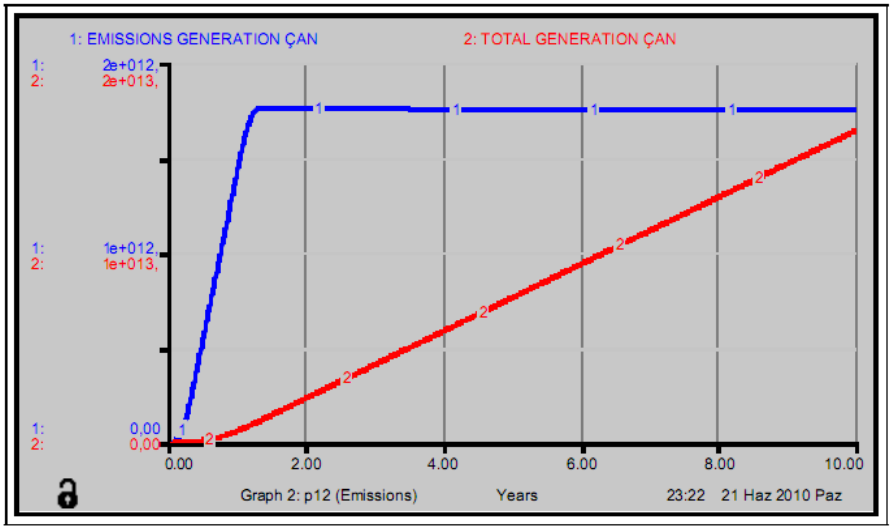


Figure 38. Emissions generation from Çan in 10 years (ton CO2)..

5.1.5 Electricity Generation and Capacity Investment Analysis

Electricity generation is not restricted to lignite power plants of EUAS, but also include other thermal capacities such as hard coal and natural gas fired power plants, hydraulic power plants, and power plants operating with renewable resources. The base scenario, assumes that the capacities of all these power plants will preserve their share in overall electricity generation, despite their variable generation costs. The difference between generation capacity and required capacity when no new investment is undertaken, and the required amount of new capacity to fulfill the demand are given in Figure 39, Table 13 and Figure 40, respectively. Decline in generation and increase in required capacity in year 8 is due to depletion of lignite reserves in Yatağan as well as decrease in generation capacities.

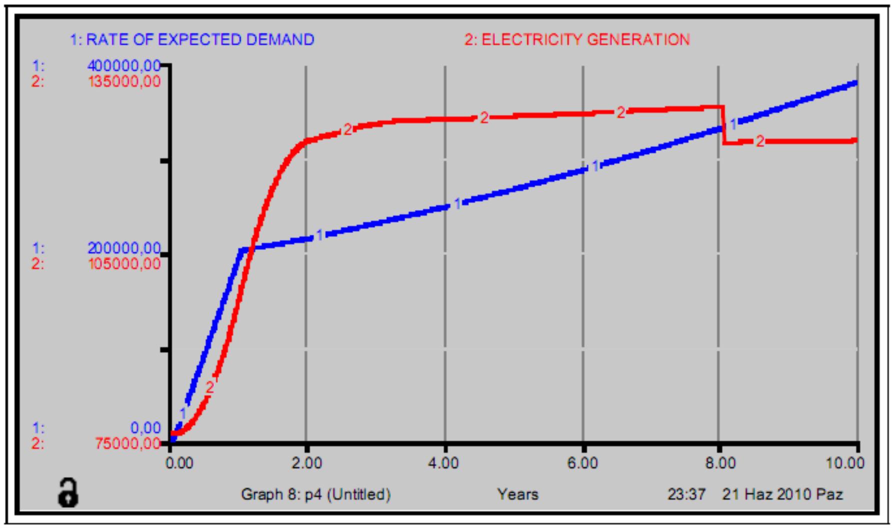


Figure 39. Electricity demand and electricity generation without new capacity investments (Gwh).

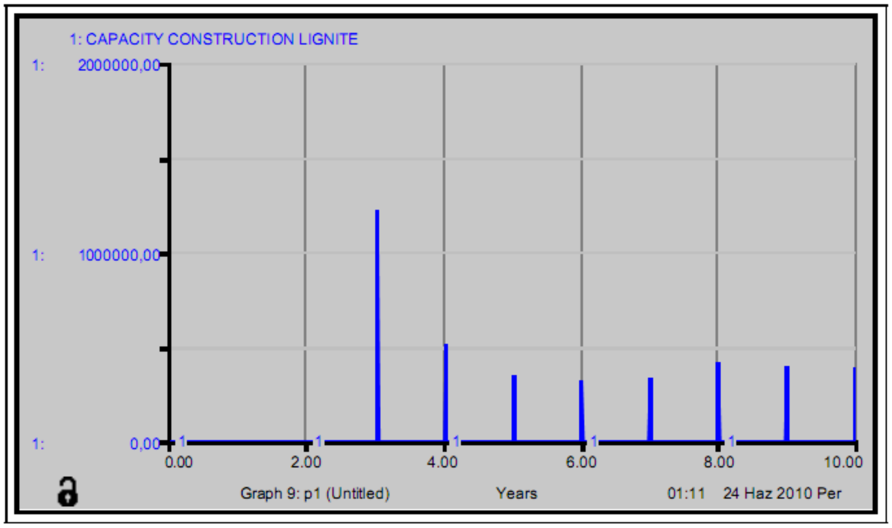
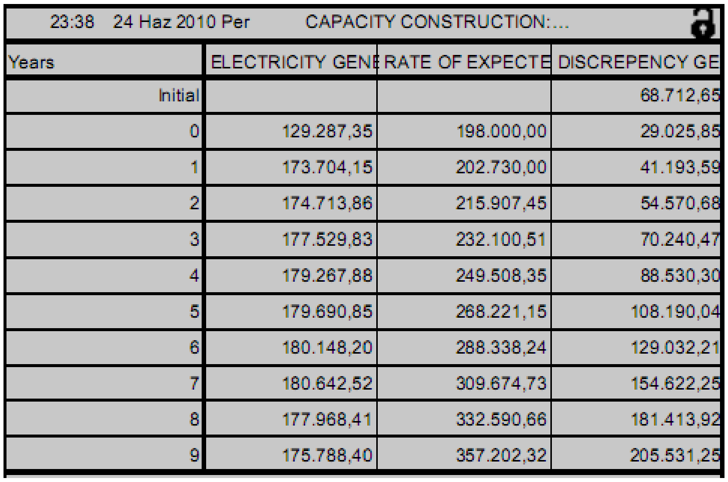


Figure 40. Required generation capacity to meet electricity demand (Mwe)

Table 13.Electricity generation, rate of expected demand and discrepancy without any new capacity addition (Gwh)



23:38 24 Haz 2010 Per CAPACITY CONSTRUCTION:...

Years	ELECTRICITY GENE	RATE OF EXPECTE	DISCREPENCY GE
Initial			68.712,65
0	129.287,35	198.000,00	29.025,85
1	173.704,15	202.730,00	41.193,59
2	174.713,86	215.907,45	54.570,68
3	177.529,83	232.100,51	70.240,47
4	179.267,88	249.508,35	88.530,30
5	179.690,85	268.221,15	108.190,04
6	180.148,20	288.338,24	129.032,21
7	180.642,52	309.674,73	154.622,25
8	177.968,41	332.590,66	181.413,92
9	175.788,40	357.202,32	205.531,25

Electricity prices are main determinants in identifying investors' behavior, and they fluctuate depending on many factors, including supply and demand of electricity. In the model, when predicted electricity price is lower 7¢$/kwh, the model uses electricity price as 7 ¢$/kwh, which approximately equals to selling price of electricity, otherwise higher value of electricity price is used in the simulation. The change in electricity price without any binding constraint on it is given in Figure 41, change in electricity price with 7¢$/kwh is given in Figure 42. Price decrease in Figure 41 is caused by increase in generation in year 1, then the price increases almost linearly with increasing demand, provided that there are no capacity additions. Again, with no additional capacity investments, but with a constraint that sets electricity price at value higher than 7¢$/kwh, the electricity price increases after year 9 (Figure 42).

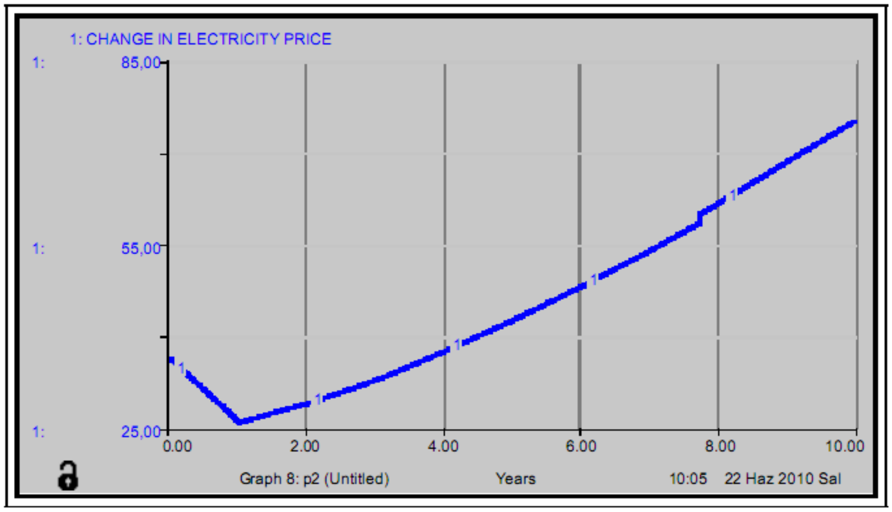


Figure 41. Change in electricity price-no constraints ($)

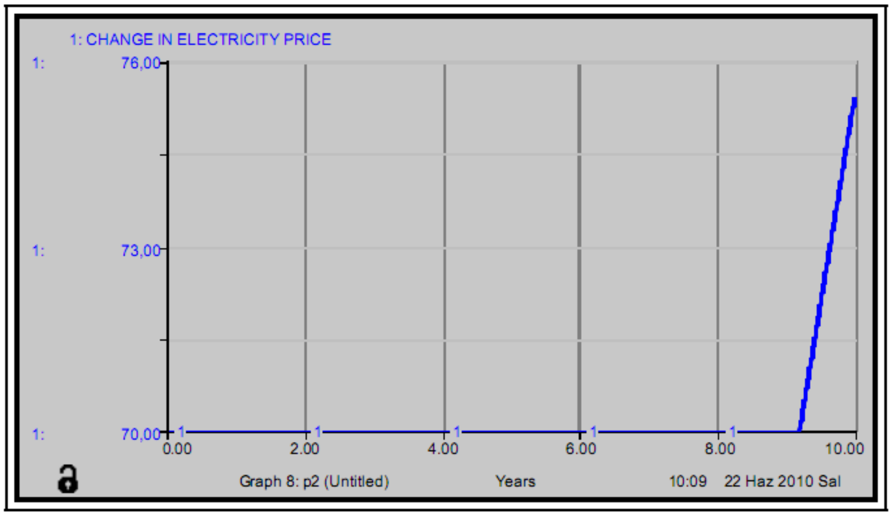


Figure 42. Change in electricity price ($)

The model then uses the electricity prices and generation costs for determining the most profitable resource for electricity generation at a discount rate of 10% (Figure 43). The expected profits are compared to identify the resource with the highest expected profit and Table 14 ranks the most profitable resource as lignite. The next highest profit expectation is observed in hard coal reserves, followed by, geothermal, hydraulic and natural gas capacities. Both wind and solar investments are not profitable at current electricity prices.

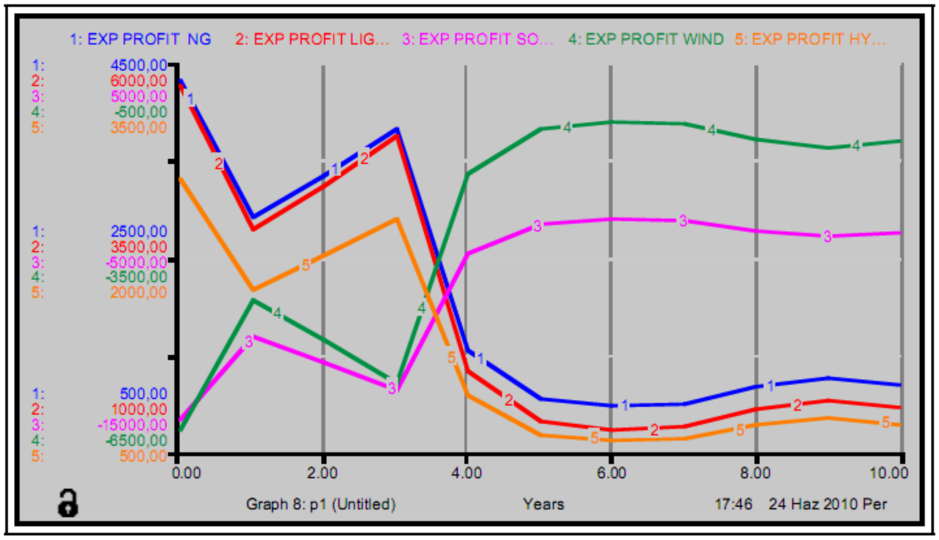
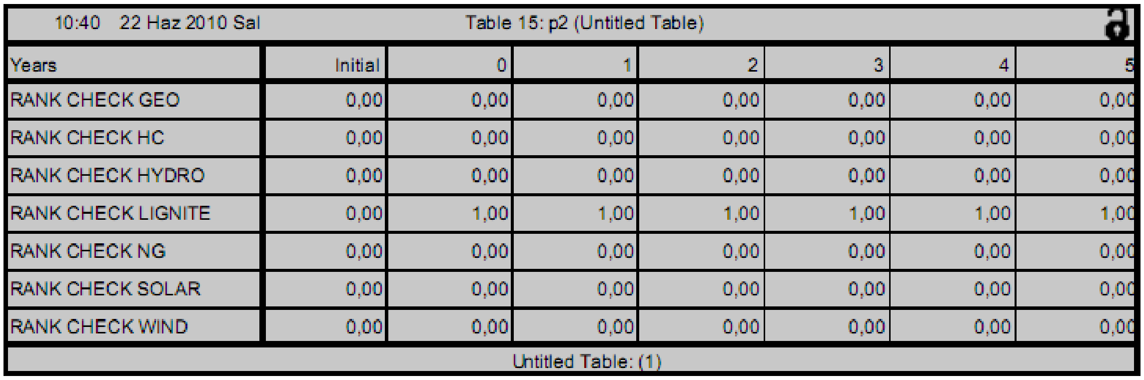


Figure 43. Expected profit for natural gas, lignite, solar, wind and hydro resources ($/MWh)

Table 14. Rank check for investment



Years	Initial	0	1	2	3	4	5
RANK CHECK GEO	0,00	0,00	0,00	0,00	0,00	0,00	0,0
RANK CHECK HC	0,00	0,00	0,00	0,00	0,00	0,00	0,0
RANK CHECK HYDRO	0,00	0,00	0,00	0,00	0,00	0,00	0,0
RANK CHECK LIGNITE	0,00	1,00	1,00	1,00	1,00	1,00	1,0
RANK CHECK NG	0,00	0,00	0,00	0,00	0,00	0,00	0,0
RANK CHECK SOLAR	0,00	0,00	0,00	0,00	0,00	0,00	0,0
RANK CHECK WIND	0,00	0,00	0,00	0,00	0,00	0,00	0,0

Assuming that all additional electricity generation capacity (9374 MW in year 1, reaching 12290 MW in year 3, and declining onwards) is going to be constructed as lignite fired plant, increase in lignite fired capacity (other than EUAS plants) are shown in Figure 44.

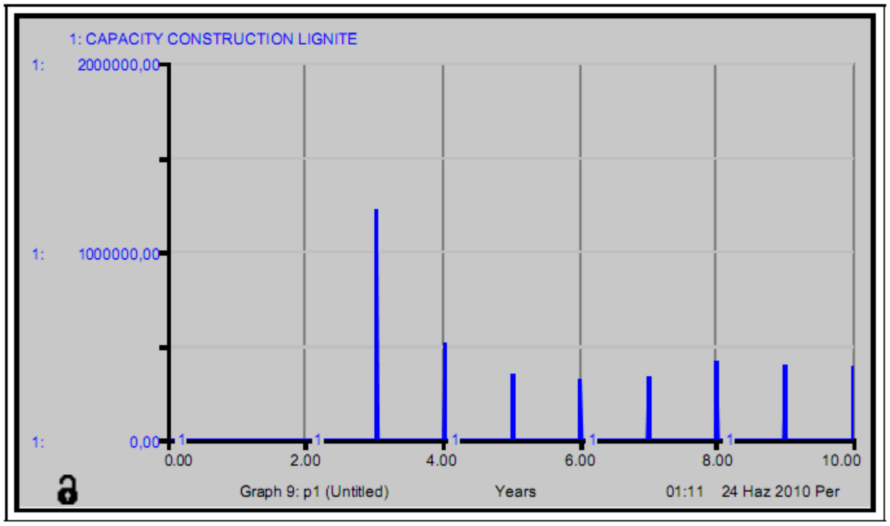
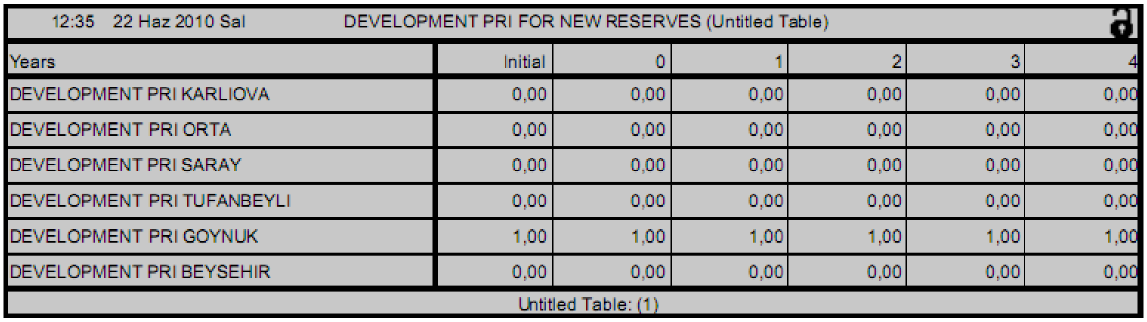


Figure 44. New lignite capacity (MWe)

5.1.6 Investigation of new reserves as potential resources for power generation

Once lignite resources are identified as resources to be developed, the base scenario assumes investing in only lignite reserves, and tries to determine the most suitable greenfield for development (Table 15)

Table 15. Development priority of greenfields



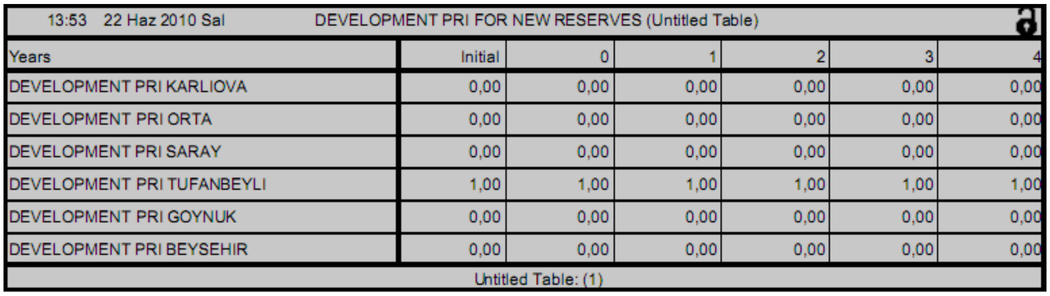
12:35 22 Haz 2010 Sal DEVELOPMENT PRI FOR NEW RESERVES (Untitled Table)

Years	Initial	0	1	2	3	4
DEVELOPMENT PRI KARLIOVA	0,00	0,00	0,00	0,00	0,00	0,00
DEVELOPMENT PRI ORTA	0,00	0,00	0,00	0,00	0,00	0,00
DEVELOPMENT PRI SARAY	0,00	0,00	0,00	0,00	0,00	0,00
DEVELOPMENT PRI TUFANBEYLI	0,00	0,00	0,00	0,00	0,00	0,00
DEVELOPMENT PRI GOYNUK	1,00	1,00	1,00	1,00	1,00	1,00
DEVELOPMENT PRI BEYSEHIR	0,00	0,00	0,00	0,00	0,00	0,00

Untitled Table: (1)

At identical plant efficiencies(ŋ=0.32), Table 15 identifies Göynük reserves as the most suitable resource to develop, however, varying plant efficiencies driven by technological development could vary the resource ranking significantly. Table 16 shows the change in development priority when technology of proposed plant is not a conventional but a fluidized bed combustion technology.

Table 16. Development priority for new reserves at with different technologies.



13:53 22 Haz 2010 Sal DEVELOPMENT PRI FOR NEW RESERVES (Untitled Table)

Years	Initial	0	1	2	3	4
DEVELOPMENT PRI KARLIOVA	0,00	0,00	0,00	0,00	0,00	0,00
DEVELOPMENT PRI ORTA	0,00	0,00	0,00	0,00	0,00	0,00
DEVELOPMENT PRI SARAY	0,00	0,00	0,00	0,00	0,00	0,00
DEVELOPMENT PRI TUFANBEYLI	1,00	1,00	1,00	1,00	1,00	1,00
DEVELOPMENT PRI GOYNUK	0,00	0,00	0,00	0,00	0,00	0,00
DEVELOPMENT PRI BEYSEHIR	0,00	0,00	0,00	0,00	0,00	0,00

Untitled Table: (1)

Considering utilization of conventional combustion technologies, amount of reserves in Göynük are insufficient to supply lignite to proposed amount of electricity generation capacity, as can be observed in Figure 45, where proven reserves deplete almost simultaneously.

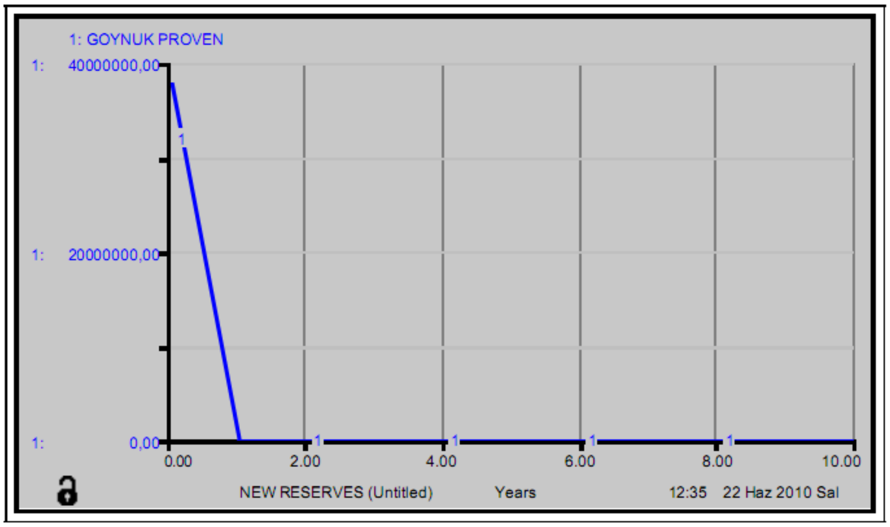


Figure 45. Depletion of proven reserves in Göynük (tons)

The simultaneous decline of selected reserve implies that a single reserve remains inadequate to meet expected electricity demand. In order to be able to generate electricity of demanded amounts, all greenfield lignite reserves are developed simultaneously. Figure 46 shows the depletion of reserves when consumed by an additional capacity of 11157.4 MW(required capacity to meet the demand generated in first two years), which fulfills the discrepancy between generation and demand. The reason of the delay in increasing generation capacity is the construction period.

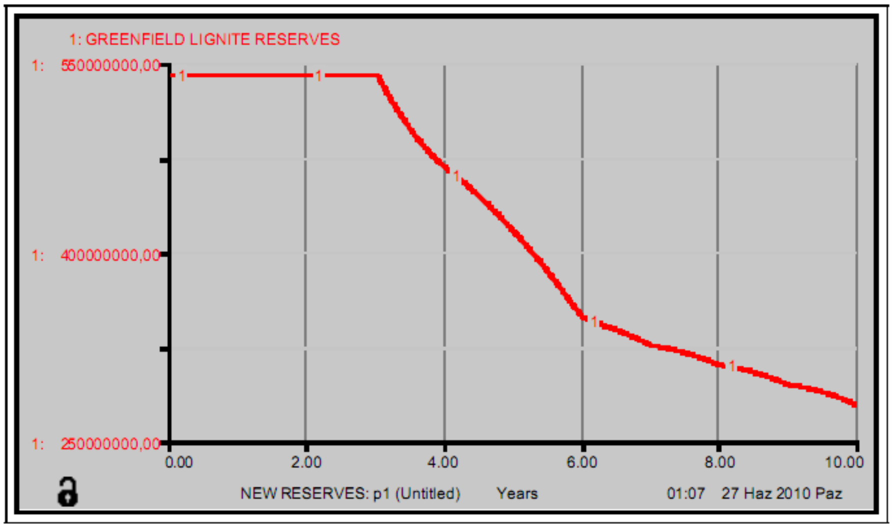


Figure 46. Depletion of greenfield lignite reserves (tons)

5.1.7 *Depletion of EUAS lignite reserves*

The model, while on one hand evaluates the possible life of greenfield areas with the construction of new power plants, on the other, calculates the depletion in EUAS reserves: The consumption of the reserves for 10 years of expected electricity demand is shown in Figure 47.

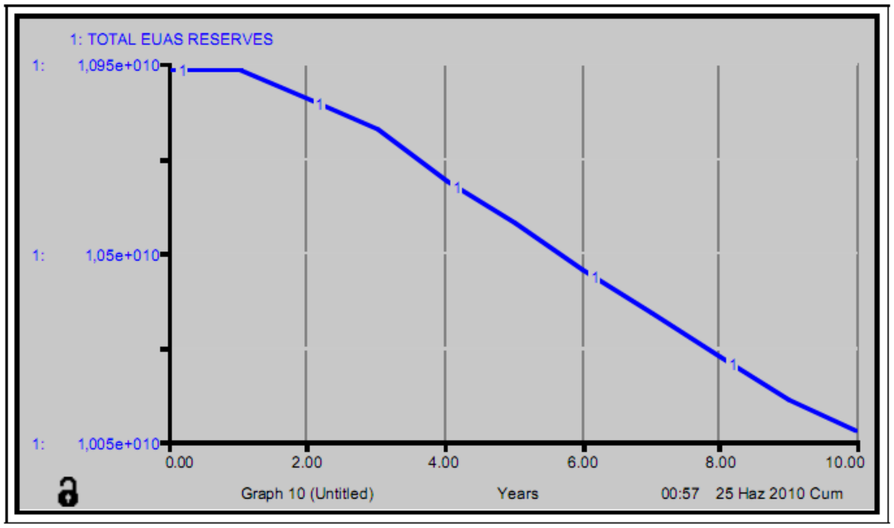


Figure 47 Consumption from brownfields(EUAS) (tons)

5.1.8 Emissions generation by coal fired power plants

Emissions generation by lignite reserves is given in Figure 48, Table 17 to Table 20 present the generation of CO2 in tons. In Table 17, it is seen that C02 generation starts in year 3 and ends in the beginning of year 6, as the reserves deplete instantly when demand is tried to be met by only greenfields.

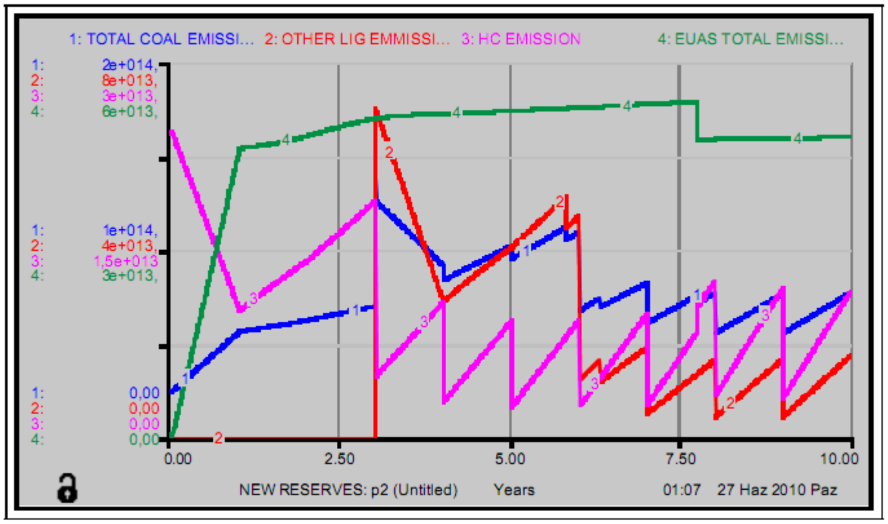
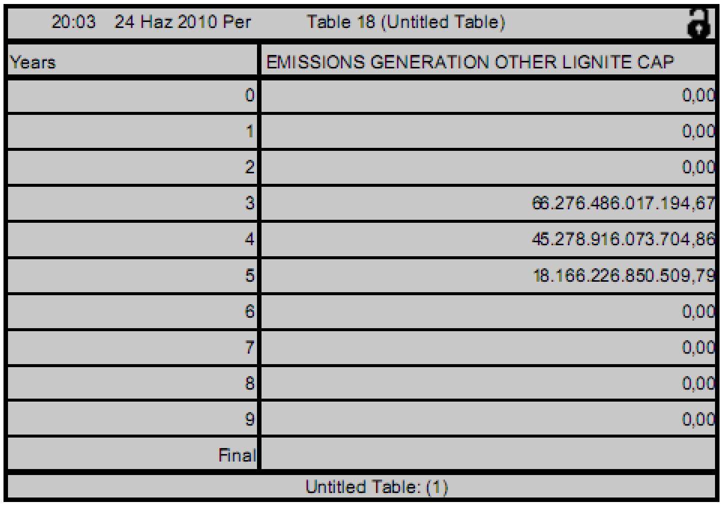


Figure 48. Total emissions when all expected demand is met by lignite resources (ton CO2).

Table 17. Emissions generation by greenfield capacities(ton CO2).

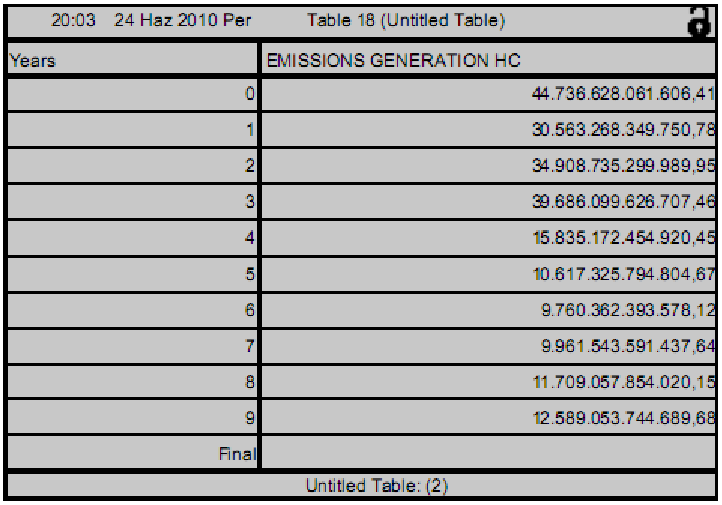


20:03 24 Haz 2010 Per Table 18 (Untitled Table)

Years	EMISSIONS GENERATION OTHER LIGNITE CAP
0	0,00
1	0,00
2	0,00
3	66.276.486.017.194,67
4	45.278.916.073.704,86
5	18.166.226.850.509,79
6	0,00
7	0,00
8	0,00
9	0,00
Final	

Untitled Table: (1)

Table 18. Emissions generation by hard coal plants capacities (ton CO2).

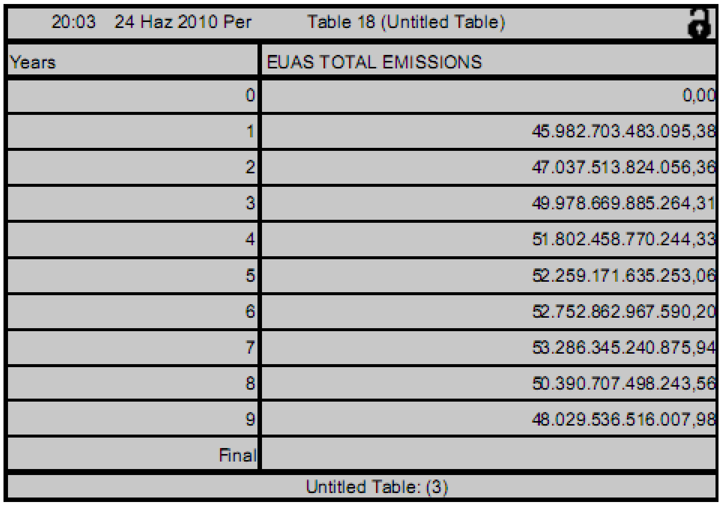


20:03 24 Haz 2010 Per Table 18 (Untitled Table)

Years	EMISSIONS GENERATION HC
0	44.736.628.061.606,41
1	30.563.268.349.750,78
2	34.908.735.299.989,95
3	39.686.099.626.707,46
4	15.835.172.454.920,45
5	10.617.325.794.804,67
6	9.760.362.393.578,12
7	9.961.543.591.437,64
8	11.709.057.854.020,15
9	12.589.053.744.689,68
Final	

Untitled Table: (2)

Table 19. Emissions generation by lignite fired power plants of EUAS (ton CO2).

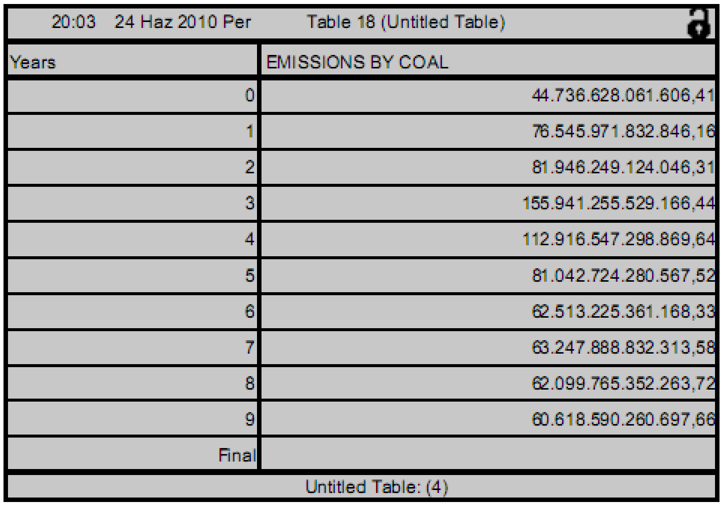


20:03 24 Haz 2010 Per Table 18 (Untitled Table)

Years	EUAS TOTAL EMISSIONS
0	0,00
1	45.982.703.483.095,38
2	47.037.513.824.056,36
3	49.978.669.885.264,31
4	51.802.458.770.244,33
5	52.259.171.635.253,06
6	52.752.862.967.590,20
7	53.286.345.240.875,94
8	50.390.707.498.243,56
9	48.029.536.516.007,98
Final	

Untitled Table: (3)

Table 20. Total emissions by coal (ton CO2).



20:03 24 Haz 2010 Per Table 18 (Untitled Table)

Years	EMISSIONS BY COAL
0	44.736.628.061.606,41
1	76.545.971.832.846,16
2	81.946.249.124.046,31
3	155.941.255.529.166,44
4	112.916.547.298.869,64
5	81.042.724.280.567,52
6	62.513.225.361.168,33
7	63.247.888.832.313,58
8	62.099.765.352.263,72
9	60.618.590.260.697,66
Final	

Untitled Table: (4)

The base scenario shows that, at the moment, the most economic means of meeting electricity demand is investing in lignite fired thermal power plants, however, lignite reserves will fail to meet expected demand in the long term. On the other hand, it is unlikely that all electricity demand will be supplied by lignite resources; the next scenario considers preserving current share of primary energy resources in the energy mix. Exploitation of lignite reserves to supply for a total of 9374 MW plants, only as a first step in meeting expected demand, also increases CO2 generation by 129.721.628.941.409,00 tons in only a period of 3 years.

5.2 Scenario 2-Preserving current energy mix

The second scenario analysis aims to investigate the effects of preserving current consumption habits. In this regard, it is assumed that, regardless of investors' profit expectations, the share of electricity investments in terms of generation resources will remain unchanged.

A basic assumption in this scenario is to distribute shares of electricity generation from fuel oil, naphtha and LPG evenly to other resources, since the electricity generating capacities consuming these fuels are being de-commissioned. The discrepancy gap provided in Table 13 is then distributed to the resources with the following shares (Table 21):

Table 21. Share of resources in second scenario

HARD COAL	6,07
LIGNITE	22,88
NATURAL GAS	29,50
RENEW.AND	0,86
HYDRAULIC	38,08
GEOTHERMAL	0,92
WIND	1,69

In Table 22, it can be seen that despite capacity increases shown in Figure 49 and Figure 50 electricity deficit does not diminish. This is due to the fact that electricity demand constantly continues to increase, however, electricity supply lags behind demand due to construction period of new facilities, which is taken constant (2 years) in the second scenario.

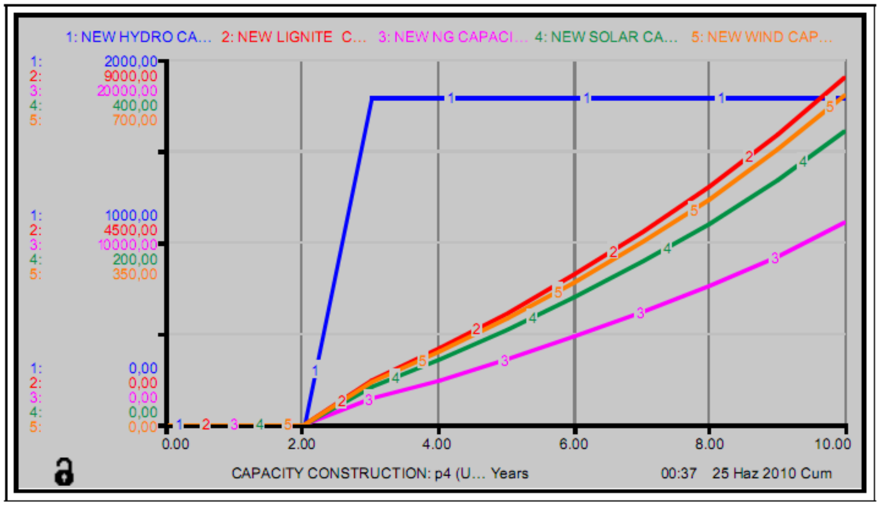


Figure 49. Addition of new generation capacities(Hydro, lignite, natural gas, solar and wind)(MWe)

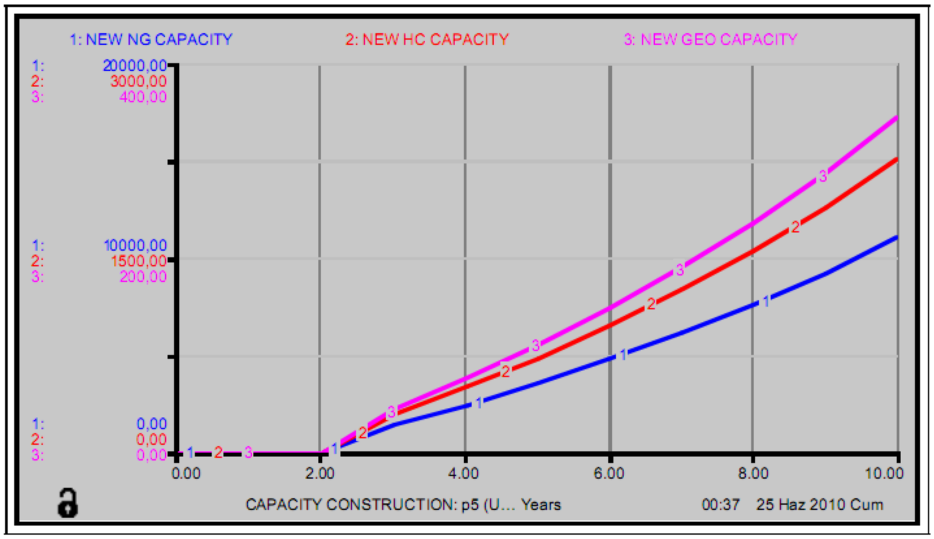
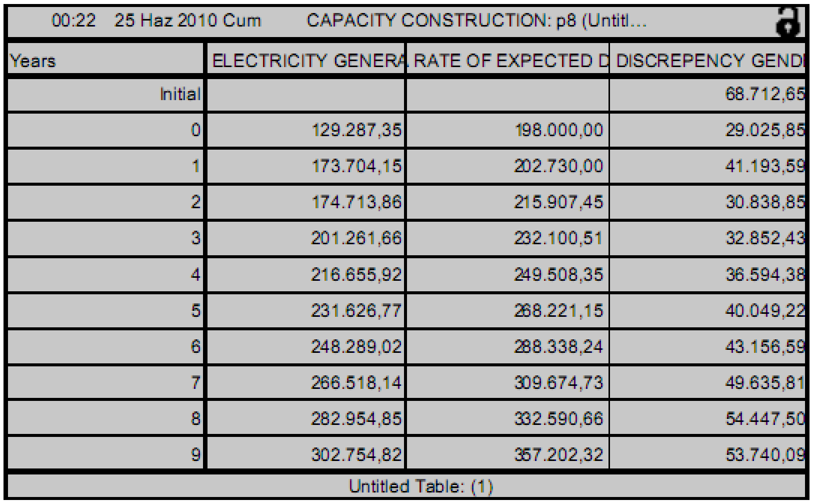


Figure 50. Addition of new generation capacities(Hard coal, natural gas and geothermal)(MWe)

Table 22. Electricity generation with additional generation capacities (Gwh)



00:22 25 Haz 2010 Cum CAPACITY CONSTRUCTION: p8 (Untitl...

Years	ELECTRICITY GENERA	RATE OF EXPECTED D	DISCREPENCY GEND
Initial			68.712,65
0	129.287,35	198.000,00	29.025,85
1	173.704,15	202.730,00	41.193,59
2	174.713,86	215.907,45	30.838,85
3	201.261,66	232.100,51	32.852,43
4	216.655,92	249.508,35	36.594,38
5	231.626,77	268.221,15	40.049,22
6	248.289,02	288.338,24	43.156,59
7	266.518,14	309.674,73	49.635,81
8	282.954,85	332.590,66	54.447,50
9	302.754,82	357.202,32	53.740,09

Untitled Table: (1)

5.2.1 *Consumption from lignite resources*

Since the generation of currently operating lignite fields do not vary with changes in expected demand, the lignite exploitation rates in Figure 47 remain unchanged. However, compared with the base scenario, both the required power plant capacity and the rate of depletion have decreased in new mines (Figure 51, Figure 52).

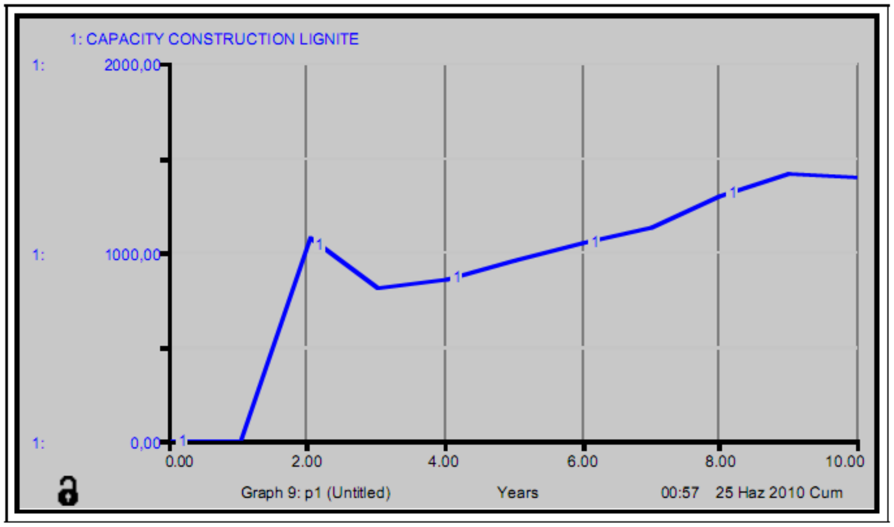


Figure 51 Increase in lignite fired power plant capacities when demand deficit is distributed among different reserves (MWe)

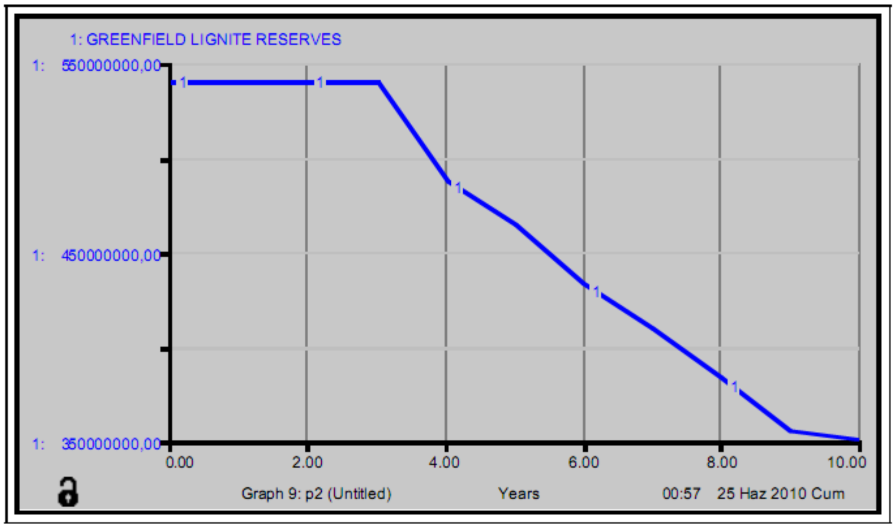
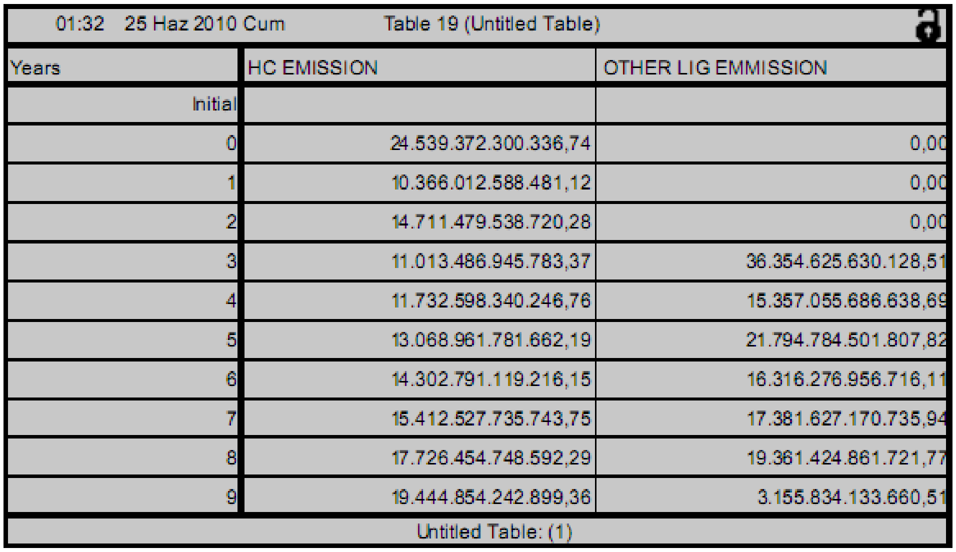


Figure 52 Depletion of green field reserves with exploitation (tons)

5.2.2 Emissions generation by coal fired power plants

CO2 generation of coal fired power plants is given in Table 24, Table 25 and Figure 53 Table 23 respectively.

Table 23. CO2 emissions of hard coal and new lignite fired capacities (ton CO2).

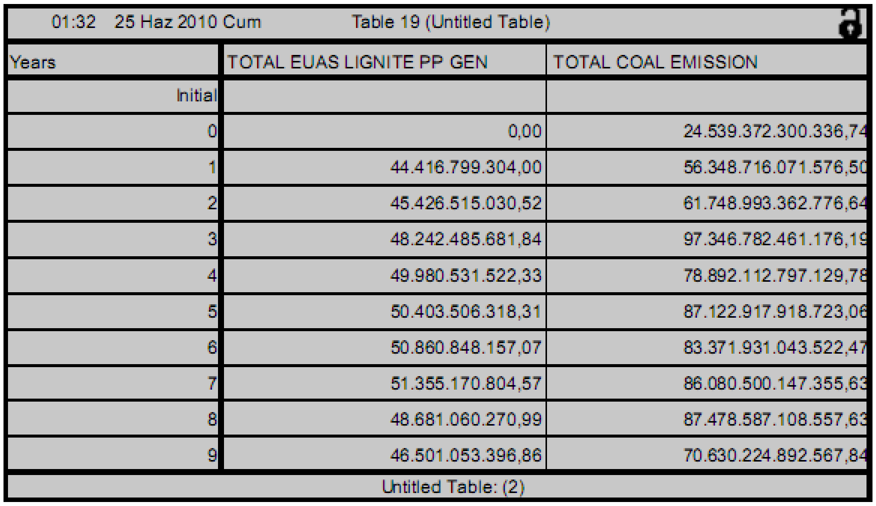


01:32 25 Haz 2010 Cum Table 19 (Untitled Table)

Years	HC EMISSION	OTHER LIG EMMISSION
Initial		
0	24.539.372.300.336,74	0,00
1	10.366.012.588.481,12	0,00
2	14.711.479.538.720,28	0,00
3	11.013.486.945.783,37	36.354.625.630.128,51
4	11.732.598.340.246,76	15.357.055.686.638,69
5	13.068.961.781.662,19	21.794.784.501.807,82
6	14.302.791.119.216,15	16.316.276.956.716,11
7	15.412.527.735.743,75	17.381.627.170.735,94
8	17.726.454.748.592,29	19.361.424.861.721,77
9	19.444.854.242.899,36	3.155.834.133.660,51

Untitled Table: (1)

Table 24. CO2 emissions of EUAS lignite fired power plants and total CO2 emissions of coal fired capacities (ton CO2).



01:32 25 Haz 2010 Cum Table 19 (Untitled Table)

Years	TOTAL EUAS LIGNITE PP GEN	TOTAL COAL EMISSION
Initial		
0	0,00	24.539.372.300.336,74
1	44.416.799.304,00	56.348.716.071.576,50
2	45.426.515.030,52	61.748.993.362.776,64
3	48.242.485.681,84	97.346.782.461.176,19
4	49.980.531.522,33	78.892.112.797.129,78
5	50.403.506.318,31	87.122.917.918.723,06
6	50.860.848.157,07	83.371.931.043.522,47
7	51.355.170.804,57	86.080.500.147.355,63
8	48.681.060.270,99	87.478.587.108.557,63
9	46.501.053.396,86	70.630.224.892.567,84

Untitled Table: (2)

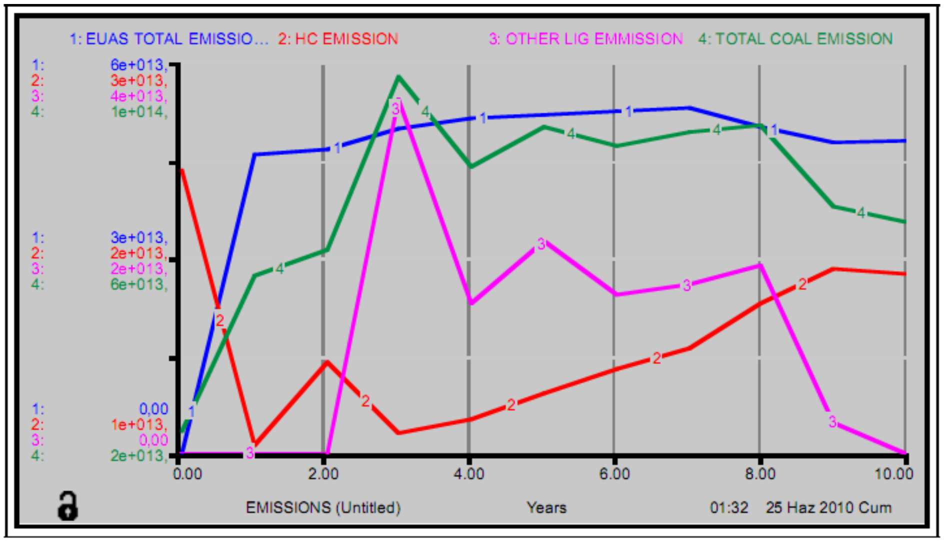


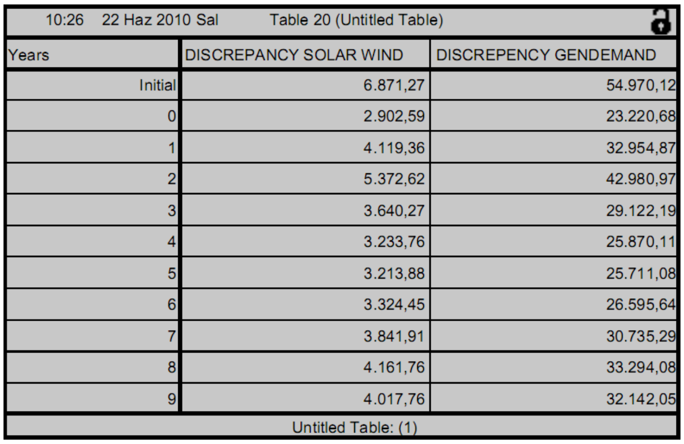
Figure 53. CO2 emissions from coal when electricity demand is met by diversified resources (ton CO2).

5.3 Scenario 3-Incorporation of learning by doing into the model

When certain portion of the difference between electricity generation and electricity demand is decided to be met by renewable resources to promote generation from renewables and sustainable electricity generation, it is required to incorporate the effect of technological progress into the model. For this purpose, learning rates for solar and wind technologies are introduced into the base model, and the time to achieve a decrease in costs of electricity generation is tried to be estimated.

The third scenario assumes that 80% of generation deficit is met by fossil fuels (lignite, natural gas, hard coal) and hydraulic and geothermal plants. Remaining 20% of the deficit is met by renewables (Table 25). The model analysis for conventional and renewable resources maximizing investors' profit expectations are given in Table 26 and Table 27 as lignite and wind, respectively.

Table 25. Distribution of generation deficit among renewable and conventional resources (Gwh/year)

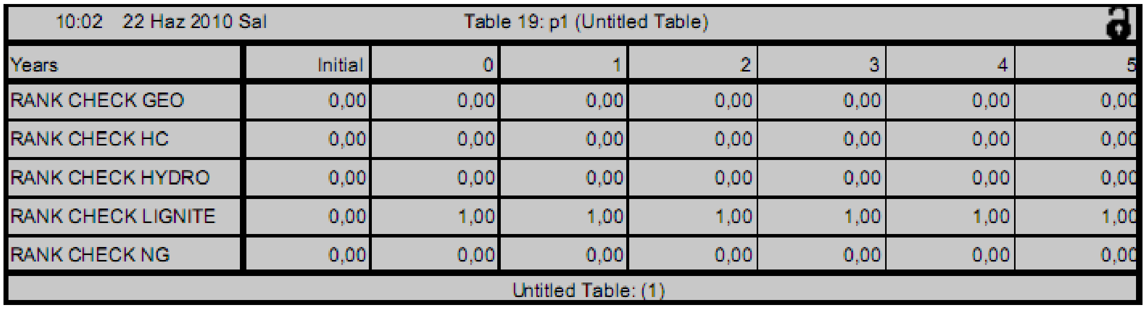


10:26 22 Haz 2010 Sal Table 20 (Untitled Table)

Years	DISCREPANCY SOLAR WIND	DISCREPENCY GENDEMAND
Initial	6.871,27	54.970,12
0	2.902,59	23.220,68
1	4.119,36	32.954,87
2	5.372,62	42.980,97
3	3.640,27	29.122,19
4	3.233,76	25.870,11
5	3.213,88	25.711,08
6	3.324,45	26.595,64
7	3.841,91	30.735,29
8	4.161,76	33.294,08
9	4.017,76	32.142,05

Untitled Table: (1)

Table 26. Most profitable conventional resource for investors

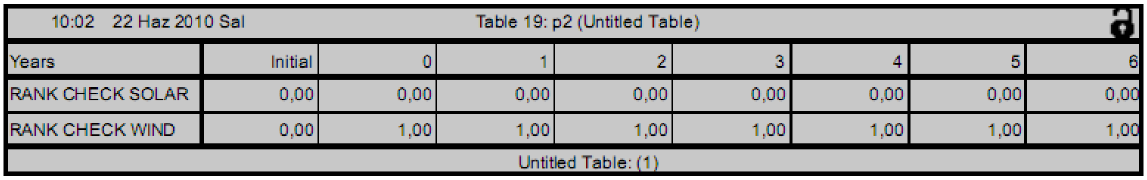


10:02 22 Haz 2010 Sal Table 19: p1 (Untitled Table)

Years	Initial	0	1	2	3	4	5
RANK CHECK GEO	0,00	0,00	0,00	0,00	0,00	0,00	0,00
RANK CHECK HC	0,00	0,00	0,00	0,00	0,00	0,00	0,00
RANK CHECK HYDRO	0,00	0,00	0,00	0,00	0,00	0,00	0,00
RANK CHECK LIGNITE	0,00	1,00	1,00	1,00	1,00	1,00	1,00
RANK CHECK NG	0,00	0,00	0,00	0,00	0,00	0,00	0,00

Untitled Table: (1)

Table 27. Most profitable renewable (solar/wind) resource for investors



10:02 22 Haz 2010 Sal Table 19: p2 (Untitled Table)

Years	Initial	0	1	2	3	4	5	6
RANK CHECK SOLAR	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
RANK CHECK WIND	0,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00

Untitled Table: (1)

Although in Table 27, wind is selected as the profitable resource, it should be noted that both technologies have negative profits with current electricity prices. Hence, in order to promote electricity generation from these resources, subsidies in electricity prices are introduced, increasing electricity selling price to 26.4 $¢/kwh for both solar and wind technologies. At this price, expected profit for wind generation becomes profitable, however solar technologies still remain unprofitable(Figure 54). Because the model assumes competitive market and consumers' choice is always maximizing the profit, development in solar technologies will not be achieved unless the model forces capacity increase in both technologies. Therefore, the generation from solar and wind is divided equally.

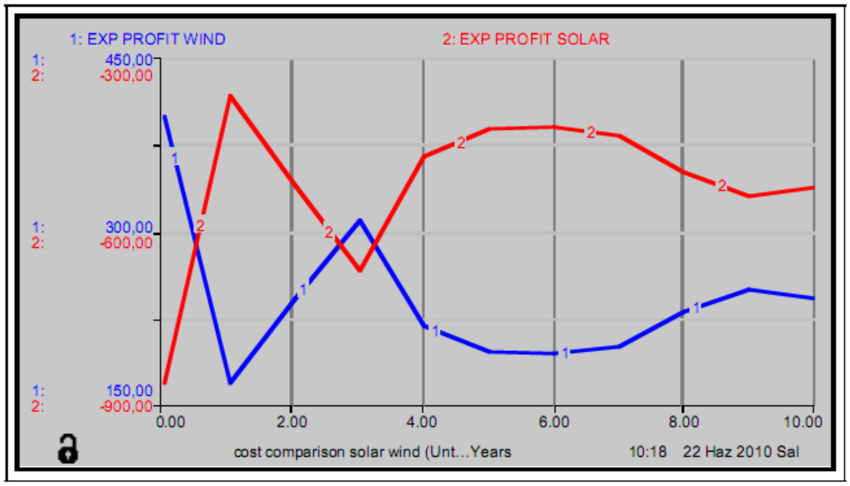
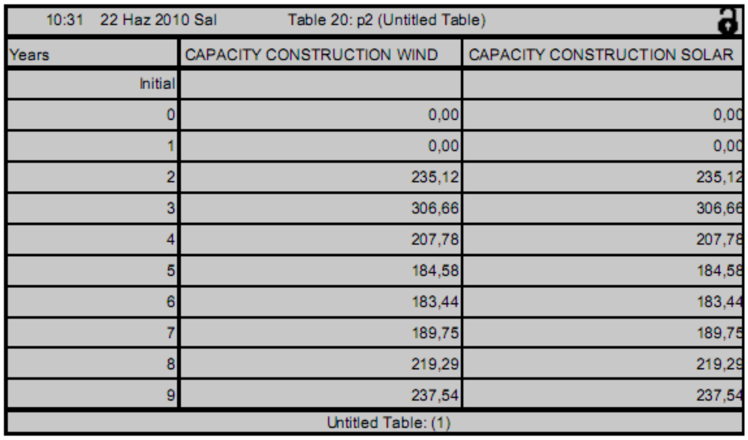


Figure 54. Expected profit from wind and solar capacities

When generation deficit is distributed between wind and solar technologies, the capacity requirements in Table 28 occurs:

Table 28. Additional renewable capacity construction



10:31 22 Haz 2010 Sal Table 20: p2 (Untitled Table)

Years	CAPACITY CONSTRUCTION WIND	CAPACITY CONSTRUCTION SOLAR
Initial		
0	0,00	0,00
1	0,00	0,00
2	235,12	235,12
3	306,66	306,66
4	207,78	207,78
5	184,58	184,58
6	183,44	183,44
7	189,75	189,75
8	219,29	219,29
9	237,54	237,54

Untitled Table: (1)

To assess the effect of learning through capacity deployment, learning rates values from reported learning rates of different technologies presented in Figure 13 is used and learning rate for wind technologies is taken as 8%, whereas learning rate for solar is assumed to be equal to 20%. Increase in generation capacities then decrease generation costs, which in turn increases the expected profit at a discount rate of 10%. The new cost of electricity generation from these technologies is calculated using Equation 1:

$$C(X_t)= C(X_o)\ (X_t/X_o)^{-b} \qquad \text{(Equation 1)}$$

The increase in expected profit of solar and wind technologies in a period of 10 years is given in Figure 55 and Figure 56, respectively.

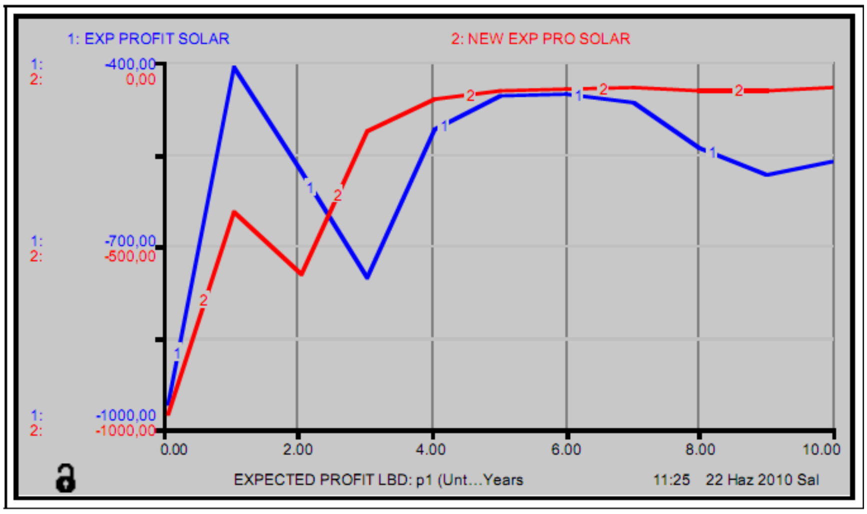


Figure 55. Comparison of expected profit from solar generation with and without learning by doing (Electricity price subsidized at 26.4 $¢/kwh)

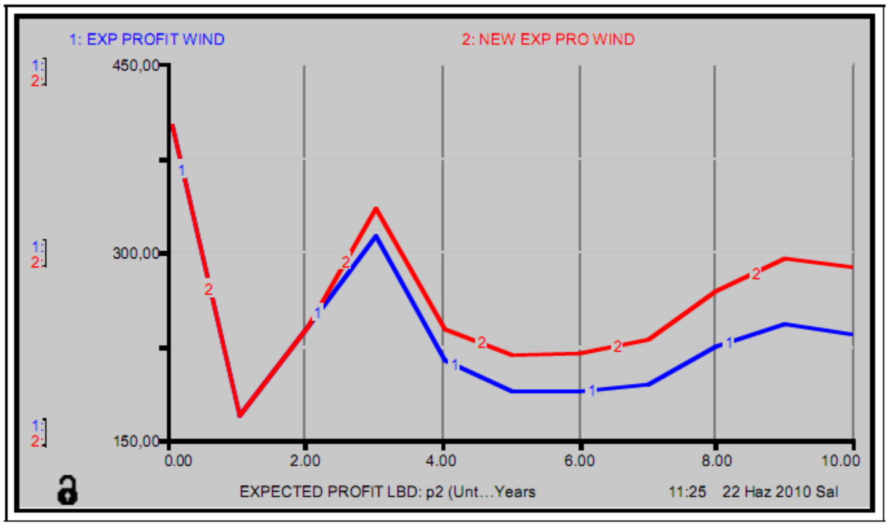


Figure 56. Comparison of expected profit from wind generation with and without learning by doing (Electricity price subsidized at 26.4 $¢/kwh)

It can be observed from the Figures above that, costs of solar technologies decline more rapidly than costs of wind. This is due to the fact that learning rate for solar is higher than that of wind. This rapid increase, however, does not make solar investments profitable but reduces the loss of investors. Hence, in order to make solar investments profitable, increase in electricity prices should be considered.

On the other hand, another point of concern is whether increase in renewable capacities makes renewable investments competitive. Expected profit of electricity generation from wind technologies is compared with generation from lignite, natural gas, hydro(Figure 57), and it is observed that, although the wind investment is profitable, wind generation cannot compete with conventional technologies in 10 years time.

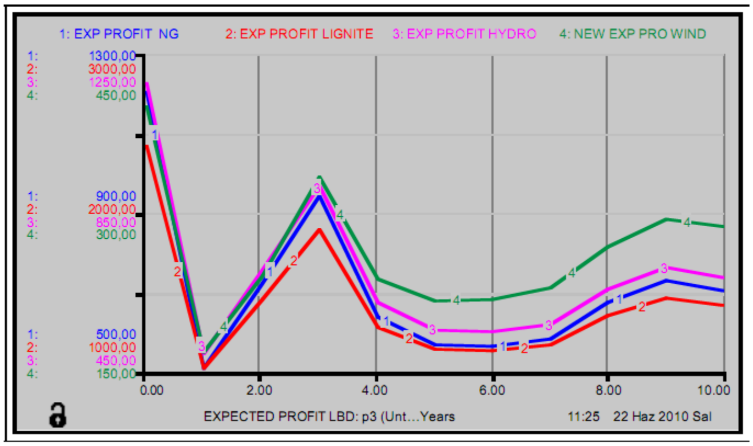


Figure 57. Comparison of expected profit from wind with conventional technologies.

5.3.1 *Depletion of lignite reserves*

The depletion of greenfield and brownfield reserves is given in Figure 58. It is observed that, compared to the base scenario, promotion of renewable energies, increases the lifetime of greenfield reserves

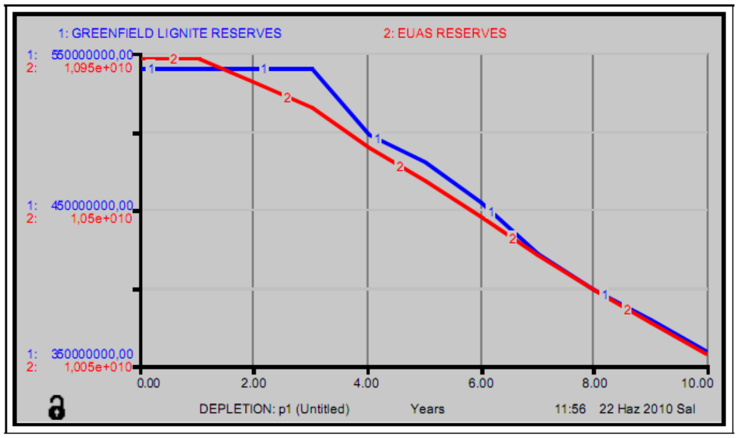


Figure 58. Depletion of reserves when renewable energy is promoted.

5.3.2 Emissions generation from coal fired power plants

The variation of CO2 emissions with promotion of renewable technologies is given in Figure 59.

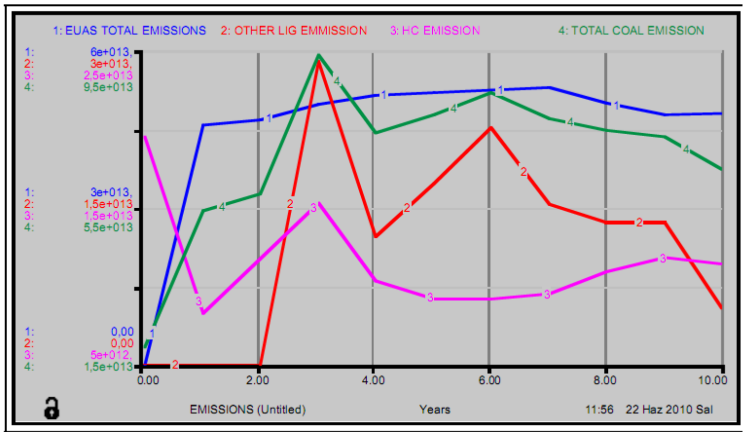


Figure 59. CO2 generation from fossil fuels, all new generation capacities are lignite fired.

CHAPTER 6

RESULTS AND DISCUSSION

After running three scenarios on the model, the basic assumptions of the model under these three different scenarios and the relevant numerical results are discussed to evaluate the optimal scenario for the investment decisions. Based on these numerical results, the outputs of the three different scenarios are analyzed to identify and construct suitable policies for investment in electricity generation capacities and new lignite reserves, and finally relevant recommendations are made .

6.1 Comparison of simulated scenarios

The changes in key elements of electricity generation policy are compared to aid designing new sustainable electricity generation policies.

6.1.1 Model inputs in different scenarios

Inputs to the model in different scenarios are summarized in Table 29.

Table 29. Summary of model inputs

Input	Scenario 1	Scenario 2	Scenario 3
Proven, Possible and Probable Reserves	Same	Same	Same
Electricity Demand	Same	Same	Same
Electricity Generation	Available capacities	Available capacities	Available capacities
Electricity Price	7¢ $/kwh	7¢ $/kwh	7¢ $/kwh
Capacity Investment	Investor maximized profit	Current share of installed capacity preserved	Renewable energy promoted, investor maximized profit
Technological development	No	No	Learning by doing

6.1.2 Model outputs in different scenarios

The results of key elements in different scenarios are summarized in Table 30.

Table 30. Summary of results of installed capacity and emission generation key elements in different scenarios.

Variable	Scenario 1	Scenario 2	Scenario 3
Installed Hydraulic Capacity(MW)	13,828	15,618.70	13,828
Installed Hard Coal Capacity(MW)	1986	4,264.11	1986

Table 30. Summary of results of installed capacity and emission generation key elements in different scenarios (Cont'd.)

Variable	**Scenario 1**	**Scenario 2**	**Scenario 3**
Installed Geothermal Capacity(MW)	81.6	600	81.6
Installed Natural Gas Capacity(MW)	10,656.80	21,728.34	10656.8
Installed Lignite Capacity(MW)	27,044.64	9,120.01	24997.54
Installed Solar Capacity(MW)	1	323.76	1765.16
Installed Wind Capacity(MW)	363.7	997.97	2127.86
Installed EUAS Capacity(MW)	7,952.1	7,952.10	7952.1
Emission generation from greenfield plants (million ton CO2)	208.539.705,89	61.153.547,02	172.411.628,55
Emission generation from EUAS plants(million ton CO2)	451,519,969.82	451,519, 969.82	451,519,969.82
Emission generation from hard coal plant(million ton CO2)	132,557,529.87	135,838,006.10	118,623,530.89
Total emission generation (million ton CO2)	792,617,205.58	648,511,522.94	742,555,129.25
Remaining Greenfield Reserve (tons)	235,014,934.75	451,428,544.61	288,063,387.17

When Table 30 is investigated, it is seen that maximum emission decline is observed in scenario 3, where renewables are promoted. Generation from EUAS power plants remain almost unchanged, as their generation capacity or rate of expected demand do not change. Despite the addition of new lignite capacities, due to short consumption period of the reserves, the lignite consumption do not have significant effect on total generation as the renewables.

Based on the results of these 3 scenario's, it can be concluded that 2nd and 3rd scenario should be implemented jointly to minimize emissions, ameliorate generation costs of electricity, both in renewable resources and lignite resources to ensure environment friendly and sustainable electricity generation.

6.2 Results and Recommendations

The basic findings of the study and relevant recommendations are discussed below:

i. Base scenario provides model validation by re-generating historical electricity generation data obtained from Thermal Power Plants report of TMMOB, Chamber of Mechanical Engineers. Under this data, model is valid.

ii. Scenario simulation in the model allows for determining behaviour of electricity investment system under different policy options, as a result the most optimal policy can be chosen for varying electricity demand through time.

iii. The result of base scenario has shown that, if all required capacity increase is met by greenfield lignite reserves, Turkey's greenfield lignites will rapidly be consumed unless new discoveries are made, therefore, diversification of ectricty generation resources is required.

iv. The second scenario in the model recognizes this problem and tries to evaluate the depletion status of these greenfield resources when current primary resource distribution pattern is preserved. Electricity demand is distributed among different resources, and greenfield reserves last longer when compared to base scenario. Level of emissions by greenfield lignite reserves are lower then those in base scenario. This scenario gives us an idea about the policy of utilizing different resources for electricity generaton

v. Third scenario incorporates technological development in renewable energies into the model by learning by doing loops and government subsidies. The analysis of these scenario's have shown that technological development is significant in making different generation technologies competitive: Wind energy which was unprofitable becomes profitable in time with increasing wind capacity. Emissions are decreased significantly. Greenfield lignite reserves last longer compared to the first scenario, but shorter compared to the second scenario.

vi. The model constructed identifies lignite resources as the most profitable resource to develop under current market condition in all scenario's, however sustainability of these resources are low in terms of both depletion and environment.

vii. Capacity investments in clean coal technologies and renewables should be promoted: The analysis of these scenarios have shown that learning by doing decreases costs significantly, and efficiencies in electricity generation increases significantly with application of new technologies.

viii. Under available data, model provides an insight to generation system, for real life applications, increasinf model details (natural gas powerplants, hydraulic powerplants, etc.) will allow for a more in depth analysis of investment decisions and resource depletion.

ix. Turkish electricity pricing system is currently being changed into balance and settlement system. When transformation is complete the model should be updated in line with the new system. Also, this study has shown that, there is a gap in the literature about discovery probabilites of lignite reserves, which is an area to be concentrated on in the future.

CHAPTER 7

CONCLUSION

It’s known that electricity is the major input to economic welfare and demand. It is also known that electricity demand constantly increases with increasing population and industrialization. Despite this situation; the resources from which majority of electricity supply is generated until 2000’s are conventional fossil fuels, which are scarce, depleting resources that endanger not only our living habitat but also electricity supply security due to scarcity.

Turkey is one of the fastest growing economies in the world with respective increase in electricity demand, which is mostly met by fossil fuels resources, especially lignite and imported natural gas. To conserve her economic growth, Turkey needs to secure and diversify its electricity generation resources.

This study aimed at developing a system dynamics model to analyze different options to secure electricity supply in Turkey. Consideration has been given to the argument that Turkey should exploit and explore her lignite reserves for securing electricity generation while deploying energy efficient and clean combustion technologies to maintain environmental sustainability. Three different scenarios are simulated on the constructed system dynamics model; base scenario being the simulation of generating all electricity demand from the most profitable reserve lignite green fields. The result of base scenario has shown that, if all required capacity increase is met by green field lignite reserves, Turkey’s greenfield lignite reserves will deplete shortly unless new discoveries are made. The second scenario in the model recognizes this problem and tries to evaluate the depletion status of these greenfield resources when current primary resource distribution pattern is preserved. Third scenario incorporates technological development in renewable energies into the model by learning by doing loops and government subsidies. The analyses of these scenarios have shown that technological development is significant in making different generation technologies competitive. Although at the moment, the model overviews the electricity generation system in Turkey without going into detail, incorporation of learning by doing loops in all generation technologies will provide more accurate and precise results in terms of both electricity investment policy analysis, reserve depletion, site selection for new power plants and emission generations.

There have been two major obstacles in model construction: The first problem is obtaining accurate data for electricity prices, electricity capacity, electricity consumption and information on proven reserves and their qualities. Because of the difficulty of obtaining up to date data, these values are taken from private sector registrations (electricity prices), government statistics (electricity capacity, electricity consumption) and from EUAS (information on proven reserves and their qualities in year 2004). The other major difficulty in this modeling effort has been the lack of risk analysis model in exploration of lignites in the literature. To overcome this gap in the model, discovery probability analysis for Zinc reserves is used, but compared with occurrences of metallic minerals; lignite reserves are abundant resources, which suggest that actual probabilities for discovery should be higher: Increased discovery probabilities are important in terms of determining the life of the reserve.

The constructed decision support system is a powerful tool for evaluating different investment alternatives in the electricity generation sector, and could be utilized by energy companies to assess different investment options in different resources and technologies. Provided that the above mentioned modeling difficulties are surmounted, outputs of the model scenarios can aid companies to structure long term investment policies, to evaluate competitiveness in new energy technologies and to comply with environmental restrictions while generating electricity to meet electricity demand.

In the future, the model can be further developed by introducing changing legal structure in the Turkish electricity legislation. Statistical and geological studies on exploration risk analysis and probability of discovery of lignite minerals is also another area for further research since there are almost no studies in the literature for more abundant minerals such as lignite.

In order to generate accurate behavior of the electricity generation system in the future, the model should be continuously updated with recent data and should reflect changes in legislation. With the incorporation of details of hydraulic plants and natural gas fired power plants, the model can also be used to make analyses in macro scale.

REFERENCES

Bunn, D., & Dyner, I. (1996). Systems Simulation to Support Integrated Energy Analysis and Liberalised Planning. *Int. Trans. Op. Research , 3* (2), 105-115.

Committee of The Australasian Institute of Mining and Metallurgy,(2004), *The JORC CODE*

Committee of The South African Institute of Mining and Metallurgy, (2000). *South African Code for Reporting of Mineral Resources and Mineral Reserves.*

Elevli, S., & Demirci, A. (2003). Türkiye Linyitleri İçin Fiyatlandırma Modeli Oluşturulması. *Madencilik , 42* (4), 27-35.

Erdoğdu, E. (2010). A paper on the unsettled question of Turkish electricity market: Balancing and settlement system. *Applied Energy* , 251-258.

Ferioli, F., Schoots, K., & van der Zwaan, B. (2009). Use and limitations of learning curves for energy technology policy: A component-learning hypothesis. *Energy Policy , 37*, 2525-2535.

Fiddaman, T. (1998). A Feedback-Rich Climate-Economy Model. *Proceedings of the 16th International Conference of the System Dynamics Society.* Quebec.

Fiddaman, T. (1997). *Feedback Complexity in Integrated Climate-Economy Models.* PhD Thesis, MIT Sloan School of Management.

Forrester, J. (1961). *Industrial dynamics .* Cambridge: MIT Press.

Forrester, J. (1992). Policies, decision and information sources for modeling. *European Journal of Operational Research , 59*, 42-63.

Forrester, J. (1971). *World dynamics.* Cambridge MA: MIT Press.

Guj, P. (2008). Statistical Considerations of Progressive Value and Risk in Mineral Evaluation. *Resources Policy , 33*, 150-159.

Haraldson, H. (2004). *Introduction to System Thinking and Causal Loop Diagrams.* Lund University.

IEA. (2000). *Experience Curves for Energy Technology Policy.* Paris, France: International Energy Agency.

IEA/OECD. (2005). *Projected Costs of Generating Energy, 2005 Update.* Paris: OECD.

IPPC (1996). *REvised 1996 IPCC Guidelines for National Greenhouse Gas Inventories,.* Bracknell, England: IPCC/OECD/IES.

Jamasb, T., & Köhler, J. (2008). Learning Curves for Energy Technology and Policy Analysis: A Critical Assessment. In M. Grubb, T. Jamasb, & M. G. Pollitt, *Delivering a Low Carbon Electricity System: Technologies, Economies and Policy* (pp. 314-333). Cambridge: Cambridge University Press.

Jannsenn, M. A., & de Vries, B. (2000). Climate Change Policy Targets and the Role of Technological Change. *Climatic Change , 46*, 1-28.

Kahouli-Brahmi, S. (2008). Technological learning in energy–environment–economy: A survey. *Energy Policy , 36*, 138-162.

Kelly, K. L. (1998). A systems approach to identifying decisive information for sustainable development. *European Journal of Operational Research , 109*, 452-464.

Manne, A., & Richels, R. (2004). The impact of learning-by-doing on the timing and costs of CO2 abatement. *Energy Economics , 26* (4), 603-619.

Manne, S. A., & Barreto, L. (2004). Learning by doing and carbon dioxide abatement. *Energy Economics , 26*, 621-633.

McDonald, A., & Schrattenholzer, L. (2001). Learning rates for energy technologies. *Energy Policy , 29*, 25-261.

Meadows, D. H., Meadows, D. L., Randers, J., & Behrens III, W. W. (1972). *Limits to Growth.* Universe Books.

Meadows, D., Meadows, D. L., & Randers, J. (1992). *Beyond the Limits: Confronting Global Collapse, Envisioning a Sustainable Future.* Chelsea Green.

Nordhaus, W. D., & Yang, Z. (1996). A Regional Dynamic General-Equilibrium Model of Alternative Climate-Change. *The American Economic Review , 86* (4), 741-765.

Olsina, F., Garces, F., & Haubrich, H. (2006). Modeling long-term dynamics of electricity markets. *Energy Policy, Vol. 34, Issue 12* , 1411-1433.

O'Regan, B., & Moles, R. (2006). Using system dynamics to model the interaction between environmental and economic factors in the mining industry. *Journal of Cleaner Production* , 689e707.

Parson, E. A., & Fisher-Vanden, K. (1997). Integrated Assessment Models of Global Climate Change. *Annu. Rev. Energy Environ 22 , 22*, 589-628.

STELLA. (2000). STELLA Technical Documentation.

TEIAS. (2008). *Turkish Electricity Generation and Transmission Co.* Retrieved 2010, from TEIAS web site: www.teias.gov.tr

TEIAS. (2004). *Türkiye Uzun Dönem Elektrik Enerjisi Talep Çalişmasi Raporu.* Ankara.

TEIAS (2008). *Türkiye Elektrik Enerjisi 10 Yıllık Üretim Kapasite Projeksiyonu (2008-2017).*

TEIAS. (2009). *Türkiye Elektrik Enerjisi 10 Yıllık Üretim Kapasite Projeksiyonu.* Ankara.

Tilton, J. E. (1996). Exhaustible Resources and Sustainable Development. *Resources Policy , 22*, 91-97.

TMMOB Makina Mühendisleri Odası. (2010). *Thermal Power Plants in Turkey Report.* Ankara: TMMOB Makina Mühendisleri Odası.

Türkiye Elektrik İletim A.Ş. Genel Müdürlüğü. (2009). *Türkiye Elektrik Enerjisi 10 Yıllık Üretim Kapasite Projeksiyonu.* Ankara: TEIAŞ.

van Vuuren, D., Strengers, B., & de Vries, D. (1999). Long-term perspectives on world metal use—a system-dynamics. *Resources Policy , 25*, 239-255.

Vardar, N., & Yumurtacı, Z. (2010). Emissions Estimation for lignite-fired power plants in Turkey. *Energy Policy , 38*, 243-252.

CURRICULUM VITAE

PERSONAL INFORMATION

Surname, Name: Alpagut, Merih Ayşe

Nationality: Turkish (TC)

Date and Place of Birth: 12 January 1978 , Ankara

Marital Status: Married

Phone: +90 312 428 21 78

email: ayse.alpagut@gmail.com

EDUCATION

Degree	**Institution**	**Year of Graduation**
MSc	METU Mining Engineering	2002
BSc	METU Mining Engineering	1999
High School	TED Ankara College	1994

WORK EXPERIENCE

Year	Place	Enrollment
2008- Present	Zorlu Energy	Planning Specialist
2007-2008	TWP Eurasia	Mine Environment Engineer
2006-2007	Ministry of Energy and Environmental Resources	Engineer
2007	Part-Time Instructor	Mining Engineering Dept., METU
2000-2006	Research Assistant	Mining Engineering Dept., METU
July 1998	OAL	Intern Engineering Student
July 1997	TUPRAG Ltd. Co.	Intern Engineering Student

FOREIGN LANGUAGES

Advanced English, Intermediate French, Beginner Spanish

PUBLICATIONS

1. Ali Kindap, Tevfik Kaya, Füsun S. Tut Haklıdır , Ayse Alpagut Bükülmez, “Privatization of Kizildere Geothermal Power Plant and New Approaches for Field and Plant”, Proceedings World Geothermal Congress 2010,Bali, Indonesia, 25-29 April 2010
2. Tevfik Kaya, Neslihan Demirci, Remzi Kaya, Ayse Alpagut Bükülmez, Volkan Dedeoğlu, “Economical Aspects of the Scale Inhibitor Injection System Operation”, Proceedings World Geothermal Congress 2010,Bali, Indonesia, 25-29 April 2010
3. Alpagut, N. Çelebi, “System Dynamics Applications in the Mining Industry”, Proceedings of the 18th International Mining Congress and Exhibition of Turkey, Antalya, TURKEY, June. 2003
4. Alpagut, N. Çelebi, “Representation of an Open Pit Mine as an Information Feedback System”, Proceedings of the 4th International Conference on Computer Applications in the Mineral Industries, Calgary, CANADA, 2003