AIR QUALITY IMPACTS OF VARIOUS HEATING SYSTEMS IN ANKARA

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ABSTRACT

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In this study, existing air quality effects of the current domestic heating systems and the case of electricity use for domestic heating in Ankara have been analyzed. For the winter season 1991-1992 heat energy used in Ankara for domestic heating has been calculated by taking into account the fuel use and characteristics of the combustion systems, and the air quality measurement results have been presented. For the hypothetical case of electricity use instead of the current domestic heating systems in the city, Industrial Source Complex-Short Term (ISCST) dispersion model has been used for six different site alternatives in and around the city and for two thermal power plants having different combustion technologies and emission characteristics in order to investigate the ground level concentrations of SO_2, NO_x and SPM. The comparison of air pollution levels of current status with the electricity use alternatives considered in this study showed that potential ground level concentrations of SO_2, NO_x and SPM should be expected to be substantially lower in the case of electricity use for 1991-1992 winter season in the city of Ankara.

Keywords: Air Quality, Urban Air Pollution, Electricity use in Domestic Heating, Sulphur Dioxide, Nitrogen Oxides, Suspended Particulate Matter.

ÖZ

FARKLI ISINMA SİSTEMLERİNİN ANKARA'DA HAVA KALİTESİ ÜZERİNDEKİ ETKİLERİ

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Bu çalışmada, halihazırda evsel ısınma amacıyla kullanılan yakma sistemleri ile elektrik kullanımı alternatifinin hava kalitesi üzerine etkileri araştırılmıştır. 1991-1992 kış sezonu için Ankara'da evsel ısınma amacıyla kullanılan enerji miktarı, yakıt tüketimi ve yakma sistemlerinin özellikleri dikkate alınarak söz konusu döneme ilişkin hava kalitesi ölçüm sonuçları verilmiştir. Kent ortamında, evsel ısınmada elektrik enerjisi alternatifinin hava kalitesi etkilerinin tahmininde ise Industrial Source Complex-Short Term (ISCST) benzetim modelinden faydalanılmıştır. Model, bir dizi senaryo kapsamında iki farklı yakma teknolojisine sahip termik santral ve Ankara içi ve çevresinde altı farklı yer seçeneği için, SO_2, NO_x ve partiküler madde yer seviyesi konsantrasyonlarının hesaplanmasında kullanılmıştır. Bu çalışmada, evsel ısınmadan kaynaklanan mevcut hava kirliliği ile elektrik kullanımı alternatifinin yaratacağı potansiyel hava kirliliği düzeylerinin bir karşılaştırılması yapılmış; elektrik kullanımı alternatifinin yaratacağı potansiyel yer seviyesi SO_2, NO_x ve SPM konsantrasyonlarının, 1991-1992 kış sezonu ölçüm sonuçlarına göre önemli ölçüde düşük olduğu belirlenmiştir.

Anahtar Sözcükler: Hava Kalitesi, Kentsel Hava Kirlenmesi, Evsel Isınmada Elektrik Enerjisi, Kükürtdioksit, Azotoksitler, Partiküler Madde.

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SYMBOLS

koe	kilogram oil equivalent
NO_x	Nitrogen oxides
SO_2	Sulphur dioxide
SPM	Suspended Particulate Matter
toe	ton oil equivalent

ABBREVIATIONS

CTPP	Conventional Coal Fired Thermal Power Plant
DİE	State Institute of Statistics
DPT	State Planning Organization
EIA	Environmental Impact Assessment
ESP	Electrostatic Precipitators
FGD	Flue Gas Desulphurization
GLC	Ground Level Concentration
ISCST	Industrial Source Complex-Short Term
LTS	Long Term Standards
NGCC	Natural Gas Combined Cycle Power Plant
STS	Short Term Standards
TEAŞ	Turkish Electricity Generation and Transmission Corporation
TEK	Turkish Electricity Authority
TKİ	Turkish Coal Managements
USEPA	United States Environmental Protection Agency
WHO	World Health Organization

CHAPTER 1

INTRODUCTION

1.1 General

In an increasingly technological world, there is a growing awareness of air pollution problems and concern about their control and abatement. Among the deleterious effects of air pollution are direct injury to human health and to animals and crops, damage to property by dusts and corrosive gases, reduced visibility, and the nuisance of unpleasant smells and odours. Such environmental problems are particularly likely to be acute in large industrialized zones and in urban areas with highly concentrated population.

In order to minimize the pollution and develop appropriate abatement and control policies it is required to assess the relationship between man's activities and the levels of pollutant in the environment. For air pollution this will imply an understanding of

- generation and control of air pollutants at their source,
- the transport, dispersion, chemical transformations in and removal of species from the atmosphere,
- the effects of air pollutants on ecosystem and materials.

The main pollutants emitted into the atmosphere and hence causing environmental problems are oxides of nitrogen (NO, NO_2), N_2O, H_2S, oxides of sulphur (SO_2, SO_3, SO_4) , oxides of carbon (CO, CO_2), suspended particulate matter (SPM) containing various organic and inorganic compounds and heavy metals and a variety of organic gases (NH_3, CH_4, non-methane hydrocarbons).

These emissions originate mainly from anthropogenic activities, although there are natural sources as well (e.g. forest fires, volcanic eruptions, sea salt spray and wind erosion). The four main anthropogenic activities contributing to air pollution are;

- mobile transportation (motor vehicles, aircrafts, railroads, ships, handling and/or evaporation of gasoline),
- stationary combustion (residential, commercial and industrial power generation and heating),
- industrial processes (mainly chemical, metallurgical, pulp-paper industries and petroleum refineries),
- solid waste disposal (household and commercial refuse, coal refuse and agricultural burning).

In this context, it is important to define air pollution with its full content. The definition for pollution given by the Royal Commission on Environmental Pollution in the UK is "Pollution occurs when enough of a substance is present in the environment to have harmful effects." More comprehensive and long-winded definitions have been given elsewhere. For instance, The Engineers Joint Council (composed of representatives from the various professional engineering associations) defined air pollution as "the presence in the outdoor atmosphere of one or more contaminants, such as dust, fumes, gas, mist, odour, smoke or vapor, in quantities or characteristics, and of duration such as to be injurious to human, plant or animal life, property, or which unreasonably interferes with the comfortable enjoyment of life and property" (Bishop, 1957).

As the above definition implies, the contaminants causing air pollution problems are various, and hence it would be a great underestimation (if not misleading) to define air pollution as the presence of only SO_x and SPM found above certain levels in the atmosphere which has been the most common interpretation in the Turkish case.

It is a well known fact that air pollution has been increasing rapidly for the last 50 years in Turkey. In many cases the pollution reaches to episode levels in urban areas especially during winter seasons, in other words, while domestic heating systems are in operation and meteorological conditions unfavouring the pollution dispersion.

In order to combat the severe air pollution problems inherent in many Turkish cities the Central and Local Governments have long been seeking for different solutions. In the same context, this study attempts to investigate different domestic heating alternatives (imported coal and natural gas fired combustion systems currently used and electricity use generated through different technologies) aiming to comment on the domestic heating strategy to be chosen in the near future.

1.2 Scope and Objective of the Thesis

Objective of this thesis is to investigate different alternatives of domestic heating with a particular focus on electricity use in order to eliminate the present air pollution problems as a prelude to develop urban pollution control strategy for future as a case study for city of Ankara. The scope extends to a brief cost analysis of the different alternatives investigated.

The focus of the study is domestic heating by electricity use generated through national sources (i.e. Turkish coal) since it has been the usual trend in most of the developed countries, although the most pronounced cost disadvantage and the electricity energy deficiency which our country is currently facing with are well appreciated. These issues are referred to in the relevant chapters of the thesis (see Table 2.2 and Table 6.1).

A specific city, Ankara, has been chosen in this study to achieve a quantitative evaluation of air quality impacts and costs of different domestic heating alternatives. Because among all Turkish cities, Ankara appears to be the most suitable case regarding the availability and reliability of the extensive data required concerning fuel use, characteristics of existing combustion systems, number of buildings and dwellings, their spatial distribution in the city, meteorology and topography. A similar study could have been conducted for any other city fulfilling the data requirements concerned. The air quality impacts of the electricity use in the city for domestic heating have been determined through simulation modeling studies taking into account different technology and site selection alternatives for the power generation.

1.3 Motivations for This Study

The major factors motivated this study are summarized below;

- There appears to be a misconception that air pollution problem has been eliminated altogether in Ankara and it would stay likewise in the future where natural gas fired combustion systems for domestic heating has been in rapid increase.
- It is true that in Ankara SO_2 and SPM emissions have been eliminated significantly and consequently there has been a continuous decrease of corresponding concentrations in the atmosphere. As a result, lower values achieved in comparison to currently effective Long Term Standards of Turkish Air Quality Regulation. However, as the rapid population increase continues, it can be expected that the decrease will cease at some point, and following this an increase in trend will appear since it would be impossible both technically and economically to supply natural gas to the whole community. Additionally, like all other fossil fuels NO_x emissions originate from natural gas combustion and the ambient NO_x concentration standards are stricter in comparison to SO_x and SPM standards.
- Continuous NO_x measurements conducted in the last three years in eight stations in Ankara show that winter concentrations already exceed the standards.
- Although the primary source of NO_x emissions is traffic, it is apparently more difficult to control traffic originated NO_x emissions in the near future as it involves

far more complicated socio-economic and legislative constraints in comparison to control of NO_x emissions originating from domestic heating.

- Besides being an important primary pollutant, NO_x emissions cause ozone (O_3) and photochemical smog formation in urban atmosphere, hence bring about some serious secondary effects. Although there is no continuous urban measurements of O_3 conducted in Turkey, assuming an increase trend in O_3 concentration would definitely not be an overstatement.
- In order to develop scientifically sound air pollution control and abatement strategies in urban areas, air quality modeling studies estimating future trends are required in parallel with corresponding cost analysis.

1.4 Outline of the Thesis

This thesis is divided into two main sections. The first section, regarding the problems of energy production for domestic heating from the perspective of air pollution, highlights environmental impacts and economic factors of concern; demonstrates the extent of the problem in Ankara with a brief inclusion of whole Turkey. The second section of the thesis is devoted to investigate air pollution impacts of different domestic heating alternatives with a particular attention on electricity use for Ankara. All analysis included in this thesis are comprehensive in nature with a brief referrals of cost, and hence targeted to serve as a preliminary step for development of air pollution abatement policy in urban areas.

CHAPTER 2

ENERGY PRODUCTION FOR DOMESTIC HEATING FROM THE PERSPECTIVE OF AIR POLLUTION

In all energy production systems potential environmental impacts and in particular air quality effects are related to technology of choice and corresponding mitigation measures as well as the site selection. For example environmental effects of air pollutants, generated from thermal power plants in rural areas or domestic heating systems in urban areas are related to the topographical, meteorological and ecological characteristics of the receptor environment. In other words, emissions having the same qualitative and quantitative characteristics will cause different effects on areas having different susceptibilities, implying the importance of site selection. On the other hand, factors such as energy loss through conversion (i.e. heat energy to electricity) and transmission losses between the point of production and consumption make the site selection process complicated and difficult. From economical point of view, the most logical way appears to be producing energy at the site of need. Producing the energy at "the site of need" means minimization of transmission losses. However, from environmental point of view "the possible nearest site" has to be taken into consideration. The differentiation between the two terms has to be strictly understood as defining the site where the environmental impacts and transmission losses both minimized, or optimized. For today's world "an absolute economical view" is insufficient and "a comprehensive economical view" including environmental costs has to be taken into consideration.

In this chapter, different alternatives for domestic heating are compared by a fairly simplistic, yet comprehensive approach. Environmental and economical factors of concern are discussed for individual domestic heating systems (i.e. fossil fuel fired stoves and boilers) as opposed to domestic heating by electricity (generated through thermal power plants) taking into account control mechanisms, legal requirements, auditing and sanctions. The quantitative results of the comparison are given in Chapters 5 and 6.

There are two main subjects of concern in energy production whether it is used for industrial heat or electricity supply or for residential heating. These are environmental and economical factors. However, before discussing these issues, a brief overview of energy budget of Turkey is given below in order to highlight the current status, targets and constraints of concern; and in Appendix A the most important energy indicators in Turkey are summarized.

2.1 Energy Production in Turkey from the Perspective of Air Pollution

Turkey's current electricity energy production serves only for industrial consumption and lightening. Although the future plans are the same (i.e. no plans for electricity production for domestic heating), there is an increasing demand of electricity due to the increase in population and standard of living. According to Turkish Electricity Generation and Transmission Corporation (TEAŞ) estimations, Turkey's electricity generation capacity will be 106.2 billion kWh in 1997, and annual increase in demand will be 8%. Therefore, in the year 2000 demand will be 130 billion kWh and 270 billion kWh in the year 2010. This implies a serious electricity energy deficit starting almost from present time. The only choice Turkey has, appears to be producing more and cleaner energy as soon as possible.

In Turkey energy consumption per capita does hardly reach to 1,000 kWh annually at present, whereas it is 8,000 kWh per capita in European Union Countries on the average and around 14,000 kWh for industrialized countries. In some of these industrialized countries electricity is also used for domestic heating. In general, electricity used for domestic heating is generated from fossil fuel fired thermal power plants, nuclear power plants, hydroenergy and a small portion from different types of energy production systems (e.g. geothermal, wind, solar energy etc.). However, coal fired thermal power plants are the main contributor to electricity energy production all over the world.

Although energy and in particular electricity energy production in Turkey is an order of magnitude smaller than developed countries, global emissions created in developed countries are only two or three times more than that of our country. Similarly and more remarkably, urban air quality in Turkey is much worse when compared to that of urban areas in developed countries, implying a significant problem generating higher concentrations with lesser emissions. For example, in Germany energy consumption per capita is 15,000 kWh per year (i.e. 15 times of that of Turkey), however, emission per capita is only three to six times more than that of Turkey (see Table 2.1). This means that in Germany although more fossil fuel is consumed and much more energy is produced compared to Turkey, emissions generated from energy production are controlled effectively.

Table 2.1 Global SO_2, NO_2 and SPM emissions in Turkey and Germany

Country	Emission per person (kg/person)			Emission per Unit Energy Consumption (kg/Toe)		
	SO_2	NO_2	SPM	SO_2	NO_2	SPM
Turkey	16	8	3	26.9	14.3	5.2
Germany	52	50	12	16.0	15.4	3.6

Source: State Planning Organisation (DPT), 1992.

Enforced by the discussion given above, it is felt that the causes of air pollution problems in Turkish cities have to be scientifically analysed and radical pollution control strategies should be developed, implemented through certain control measures. In this context, extensive use of individual domestic heating systems (i.e. stoves and boilers) can not help to solve the problem. Because these systems are operated without any or with a very limited control of combustion and fuel, and without any impact assessment procedures which would otherwise help foreseeing the influences to be expected. At this point it is crucial to make a comparison between individual systems and electricity use in domestic heating for environmental and economical factors of concern.

2.2 Environmental Impacts

Environmental effects or related environmental costs of energy production systems can be defined as the "negative impacts or losses" encountered in the receptor environment. Energy production activities cause negative impacts on the receptor environment (air, water, soil), on living species in that area (human beings, animals, plants) and on materials having economical, cultural and historical importance (i.e. buildings, bridges, historical monuments)[1]. The factors determining the scale and controllability of the potential impact is not only the amount of pollutants but also the characteristics of the receptor area (its self-cleansing capacity and sensitivities of the living organisms) and applicability of the legal requirements and sanctions. Therefore, three major factors to be considered in the context of air quality effects of energy production or in particular domestic heating activities are i) emission minimization, ii) site selection, and iii) legal requirements, auditing and sanctions.

Among those, emission minimization is related with the fuel, process (combustion) technology and control (treatment) technology. However, in the local scale, emission minimization does not mean a proportional improvement in air quality since emissions and concentrations are directly but not linearly related. Transport, dispersion, chemical transformations in and removal of species from the atmosphere are functions of topographical and meteorological setting of the activity area. Additionally, the same level of pollutant concentrations have different impacts on different receptor environments, therefore site selection is of significant importance. Finally, planning the activities regarding site selection and fulfilling the commitments regarding emission minimization must be under legal control through auditing and sanctions.

2.2.1 Emission Minimization

Energy production systems in this context are either boilers and stoves used for domestic heating, or industrial heat and electricity production systems or thermal power plants. In all those activities of concern, in order to minimize emissions and air pollution, the first

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1 Another important point for the environmental impacts of all energy production activities is socio-economical; neverthless it is not in the scope of this thesis.

issue of consideration have to be the current air quality status of the facility area or the current emission load. When an activity requiring use of fossil fuel is of concern and if the current emission load exceeds certain limits or tend to reach a certain level, permissions should be given after a very careful examination of the potential impacts. If the pollution level is above the limits permission to any type of energy production activity should be given after analysing the potential impacts of the proposed activity on the environment very carefully. In parallel to this assessment necessary measures have to be put into practice for reducing the emission loads originating from the existing energy production systems. For the case of residential heating in urban areas in Turkey, such an approach is not in practice up until the date.

2.2.1.1 Fuel

Emissions generated from any type of energy production systems are directly related to the physical and chemical characteristics of the fuel. Therefore, fuel selection is one of the key points to reduce emission levels. For the case of coal use, there is a wide variety of techniques available to enhance the fuel quality by means of enrichment processes, gasification, coking, liquification, briquetting and coal treatment aiming to produce higher calorific value with lower pollutant characteristics.

The first step in this context is to select the cleaner fuel having lower sulphur, ash and humidity content. In the Turkish case where the in-country coal assets can not fulfil these requirements there are two alternatives to reduce the emission level; either imported low-sulphur coal or natural gas should be used or relatively high-sulphur in-country lignites, after certain enrichment processes. However there are significant economical handicaps[2] in the case of using foreign sources, i.e. natural gas and imported coal. It is rather controversial to choose expedient measures which would lead to severe foreign dependency on such a primary issue as energy in the Turkish case. However, our national

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2 In 1990, energy import was accounted for some 31.4% of Turkey's overall export. This indicates a curicial 60% foreign dependency of our national economy (TMMOB, 1995). Therefore, an energy planning policy based on the most realistic use of Turkish lignite (accounting about 8.6 billion ton) and brown coal reserves (1.3 billion ton) should be considered as a must.

fossil fuel sources are very poor in quality and should only be used after necessary enrichment processes in parallel with the most efficient combustion technologies.

At present 20% of the total energy consumption in Turkey is met by the combustion of in-country lignites. The amount of lignite utilization in the total energy consumption in the year 2000 is expected to be doubled compared to the present. The prevalent characteristics of Turkish lignites are high volatile matter, moisture, ash, and sulphur contents and low calorific value. Turkish lignites have a mean humidity content of 31%, mean ash content of 22%, mean volatile matter content of 26%, a mean total sulphur content of 2% and a mean heat value of around 1,800 kcal/kg (Atımtay and Özenirler, 1995). The main characteristics of the Turkish Lignites are given in Table 2.2 and the distribution of sulphur forms in Turkish Lignites are given in Table 2.3.

Table 2.2 Characteristics of the major Turkish lignite reserves

Source	Total Reserve (10^6 ton)	Ash Content (%)	Moisture (%)	Volatile Matter (%)	Lower Calorific Value (kcal/kg)	% Dry Ash Free			
						C	H	S	N
Zonguldak	539.20	13.30	9.60	24.40	6,649.23	87.30	5.10	0.50	-
Tunçbilek	220.30	24.90	20.80	24.30	3,634.04	74.50	5.50	1.40	2.95
Soma	515.00	23.50	15.10	32.10	3,723.85	73.50	4.80	0.90	1.12
Çan	128.30	30.40	21.40	25.50	2,795.45	66.10	5.50	8.40	2.25
Seyitömer	228.60	14.80	31.00	28.40	3,254.75	70.00	5.00	2.00	-
Orhaneli	58.50	24.20	26.80	24.60	2,675.55	69.40	5.60	3.20	-
Beypazarı	222.00	34.80	22.10	15.10	2,456.05	70.80	5.80	7.30	2.50
Yatağan	535.10	15.80	37.30	28.20	2,535.83	-	-	3.90	-
Saray	143.00	16.80	44.90	19.20	1,976.69	-	-	6.30	-
Kangal	176.00	21.00	48.30	19.80	1,357.84	-	-	7.50	-
Elbistan	3539.00	23.30	49.50	18.30	1,117.80	66.20	5.50	2.70	-
Seyitömer	1000.00	68.50	5.00	25.70	2,995.13	13.20	2.00	-	0.30
Göynük	2500.00	32.00	-	-	3,038.12	56.00	6.75	1.45	1.40
Beşşehir	130.00	24.60	45.80	-	1,098.69	-	-	3.71	-

Source: Ataköl, 1993.

There are combustion difficulties in conventional combustors associated with the low ash sintering temperatures. For these reasons, there is a major air pollution problem in the large cities of Turkey during winter months (Atakül, Öner and Yardım, 1993).

As presented in detail in Table 2.2 and Table 2.3, poor quality Turkish lignites have to be processed before use for the environmental matters of concern. Application of enrichment and treatment techniques are not optional any more but becomes a must worldwide to solve the air pollution problems and to ensure the stack gas emission limits and receptor area concentration levels are not exceeded (Hucko *et al.*, 1988).

Table 2.3 Distribution of sulphur forms in Turkish lignites

Source	Sulphate (%)	Pyritic (%)	Organic (%)	Combustible (%)	Reference
Tunçbilek	3.39	40.68	55.93	-	1
	25.67	27.93	46.40	68.92	2
	41.17	8.95	49.88	97.95	3
	6.20	7.70	86.22	90.13	4
Beypazarı	12.52	18.79	68.69	-	1
	22.83	28.29	48.87	55.94	2
	10.29	32.13	57.58	86.23	3
	21.28	27.86	50.14	26.66	4
Soma	2.86	41.43	55.71	-	1
	5.15	32.99	57.73	45.36	2
	17.15	33.81	49.05	26.66	3
Çan	19.62	25.28	55.10	-	1
	28.59	14.74	56.67	98.60	2
Yatağan	6.10	18.50	66.59	-	1
	11.38	14.37	74.25	48.50	2
Elbistan	3.92	3.27	92.81	-	1
	28.44	11.70	60.10	51.60	2
Seyitömer	11.23	35.18	53.80	-	1
	36.05	35.19	28.75	41.63	2
Kangal	11.73	35.18	53.90	-	1
Karlıova	16.35	21.61	62.03	-	1
Beyşehir	19.82	75.77	4.40	-	1
Mergen	9.80	19.14	71.06	-	1
	0.64	17.64	81.72	97.94	2

1. Gürüz *et al.* (1987), 2. Gürüz and Çelebi (1979),
3. Küçükbayrak (1984), 4. Ceylan and Olcay (1987)

There are basically three physical processes feasible for the enrichment of coal; namely sizing, washing and drying. Sizing process applied by means of crushing and sieving. By the use of these processes coal size is optimized for efficient combustion. Washing processes are applied to minimize the ash, pyritic and sulphate originated sulphur content in the fuel. Drying processes are on the other hand, effective in reducing the excess water of coal. By the use of these techniques, i) CO, H_xC_y (hydrocarbons) and SPM emissions will be reduced significantly. ii) heat value will be increased substantially because of lower water and ash content, consequently amount of fuel used for unit energy production will be reduced which results in decrease of emissions per unit energy production, iii) transportation of coal bearing lower water and ash content will be more economical, and iv) although there will be no change in SO_2 emissions originating from organic sulphur in coal, pyritic and sulphate originated SO_2 emissions will be minimized. The level of enrichment through those physical processes is directly dependent on the characteristics of the tuvenan coal and the characteristics of the techniques applied (Wheelock and Markuzewski, 1981). There are some chemical and biological techniques of organic sulphur removal from coal (Doğan and Çelik, 1992) yet they are not found to be feasible at the present time. However, in the future by means of technical and economical improvements these are expected to become applicable (Bos *et al.*, 1986, Hucko *et al.*, 1988).

2.2.1.2 Process (Combustion) Technology

The second important point for emission minimization is the selection of process (combustion) technology. Among the combustion emissions, CO, H_xC_y and NO_x levels are particularly related to the characteristics of the combustion system and its operational efficiency.

In a combustion process two main parameters determining the combustion efficiency are CO and H_xC_y emissions. An efficient combustion results in lower amount of CO and H_xC_y emissions. To ensure the efficient combustion process high turbulence, high temperature and long enough residence time is required in the combustion system. In addition, careful control of the excess air (oxygen) in the flame, reaching a high combustion temperature and optimal air-fuel contact results in even lower emission levels. NO_x emissions generated form combustion processes are formed in two different ways. First one is originated from the nitrogen content of the fuel and the second one due to the reaction of free nitrogen in the atmosphere with oxygen at high temperatures in the combustion systems. The main factors affecting the amount of NO_x emissions can be summarized as; the temperature of the flame and the temperature in the boiler, residence time of gases in the flame, cooling speed of gases and the excess oxygen content in the flame. In the case of coal, use of fluidized bed combustion systems, limestone injected and cycloned combustion systems will enhance the minimization of all CO, H_xC_y, SO_X, NO_x, PM emissions (Flagan, 1988).

In light of the above discussion, design of the combustion system suitable for the characteristics of the fossil fuel used, proper operation and careful control of certain technical details will result in significant reduction in the emissions since an efficient combustion of concern strictly depends on the fuel and combustion system used.

However, an important point needs to be highlighted is where and how an efficient combustion processes can be achieved both theoretically and practically. In the case of large energy production facilities such as coal fired power plants, combustion efficiency will be much higher where the process is specifically designed to achieve maximum efficiency (in other words, maximum energy production with the use of minimum amount of fuel) and operated under strict control by professional staff. On the contrary, in the case of small combustion systems such as stoves and boilers combustion efficiency is lower where the design of combustion system does not necessarily suitable for the fuel used and operated without any proper control by non-professionals. This is quite significant in terms of its implications for air pollution, meaning higher fuel consumption and consequently higher emission levels per energy produced.

In a thermal power plant heat energy is converted to electricity, therefore, thermal efficiency of a thermal power plant is lower than stoves and boilers. According to the studies carried out in Ankara, the thermal efficiency of imported hard coal fired boilers is around 62% (Durmaz and Ercan, 1992) and that of stoves is around 50% (Durmaz et.al., 1995). On the other hand there is a wide variety of technological alternatives to increase the thermal efficiency in power plants. For example, in a coal fired conventional power plant, thermal efficiency is between 30-35% while for a combined cycle heat and energy plant (in which the waste heat is used again in the water vapour cycle) it is between 50-54%. For the combined cycle power plants any type of fuel, natural gas, liquid fuels and also gasified coal can be used and in near future the efficiencies are expected to increase upto 58.5% (Özgürel and Egeli, 1994). In addition, according to a study by Şahin and Bekdemir (1994), considering investment, fuel, operation and maintenance costs, combined cycle power plants are more economical when compared to the conventional coal fired thermal power plants and nuclear power plants.

In Turkey, stoves are used commonly for domestic heating in the poorer areas of cities. This has motivated certain studies to develop better stoves having higher thermal efficiency, lower emission characteristics and overall more suitable to the Turkish lignites (Durmaz *et al.*, 1995). However, the design of the better stoves alone will not able to solve the problem as the continuous control and maintenance of the systems are not an easy target. Hence the efficiency of the system in practice is not likely to reach to the theoretical values. In the last decade of the 20th century there is almost no logical explanation left for individual domestic heating systems by means of stoves and boilers. And let alone local air quality effects of domestic heating by the use of primitive stoves, they have been led to serious problems in indoors. Only in İstanbul in November-December 1995 and January 1996, within three months 24 people died due to the poisoning from toxic gas leakage from coal fired stoves (Yeni Yüzyıl February 6, 1996).

2.2.1.3 Control (Treatment) Technology

Once emissions are reduced by the use of cleaner fuel and appropriate combustion technology selection, they can be further reduced by the application of control (treatment) technologies. However, the applicability of the control technologies, explained in detail below, will be different theoretically and practically for different type of energy production activities. First of all, cost of investment and operation of the control technologies are rather high. Second, these technologies can not be applied to small, dispersed and discrete energy production facilities (such as stoves and boilers). However, these technologies are applicable and can easily be improved for large energy production facilities, especially thermal power plants. Besides, it is necessary for proposed power plants to assure the effluent limits. Cost benefit analysis will show that employing control technologies are even profitable when environmental costs are taken into account.

Particulate Matter: Particulate in the form of dust, smoke, flyash and the like are generated by a variety of chemical and physical processes in the combustion chamber. These effluents exhibit a range of particle size and chemical composition depending on characteristics of the fossil fuel and combustion system used. In case of coal use, particles relatively large in size remain in the furnace, but smaller particles are emitted to the atmosphere with the flue gases. Flyash effluents escaping from power plants and being emitted into the atmosphere are further contaminated with trace elements suspended on the flyash particles. These elements (Al, Ba, Ca, Ce, Cs, Fe, K, Mg, Mn and Th) remain condensed at the temperature of coal combustion and divide equally between fly ash and bottom ash; As, Cd, Cu, Pb, Sb, Se and Zn which are volatilized and will, therefore, be depleted from the slag and bottom ash and condense out on the smaller fly ash particles; Br, Hg and I which are volatile and mostly remain in the gas phase, depleted in all ashes (Güney, 1994).

Pollution control techniques are well established in order to collect effluent particulate efficiently. These include mechanical cyclone collectors, electrostatic precipitators and fabric filters and baghouses, and wet scrubbers. Only electrostatic precipitators and fabric filters are able to carry out the collection of particles with an overall efficiency of 99.5% or more, so meeting the strict emission standards economically (Güney, 1994). All thermal power plants in Turkey have electrostatic precipitators. Their efficiencies and capital, operational and maintenance costs are given in Table B.3 in Appendix B. Particle removal efficiency is also related to the size of the particles. While almost 100% of the particles having a diameter of 10μm or more can easily be removed, only 5 to 10% of particles having diameter smaller than 1μm can be removed by electrostatic precipitators.

Proper operation, careful and periodical controls are crucial for the proper operation of treatment technologies as in the case of combustion technology.

Treatment technologies for SPM as discussed above are only applicable to the large power generating and industrial facilities. These technologies can not be applied to the individual heating systems.

Sulphur Oxides: There are different control technologies available for the removal of sulphur oxides generated from the combustion of fossil fuels and yet studies on the removal of sulphur oxides are still continuing densely. Flue Gas Desulphurization (FGD) methods are mainly, wet, semi-wet and dry techniques. In detail, limestone-dolomite injection, limestone washing systems, magnesium oxide washing systems, ammonium sulphate processes, catalytic oxidation techniques and Wellman-Lord processes can be stated. Target of these control technologies is the absorption of SO_2 by a chemical substance as a result of a chemical reaction. The resultant chemical substance can be reused or can be changed to a new form having economical value.

In Turkey, Çayırhan thermal power plant has FGD facility. In Appendix B characteristics and economical data on FGD for potential installations are given.

In general, with today's technology, 95% removal of SO_2 is successfully achieved (Sadakata, 1991) in FGD systems and in some as high as 98%. Besides, there is a new technology called NOXSO in which 90% of the SO_2 and 70-90% NO_x removal can be achieved (Bolli *et al.*, 1991).

FGD systems have to be designed suitable for the flue gas characteristics and the system has to be controlled regularly so as to achieve a certain efficiency for the removal of sulphur oxides. Such systems are only feasible in large power generation or industrial facilities.

Nitrogen Oxides: Nitrogen oxides are important air pollutants, the primary anthropogenic source of which is combustion. Motor vehicles account for a large fraction of the nitrogen oxide emissions, but stationary combustion sources ranging from electric power generating stations to gas-fired coking stoves also release nitrogen oxides.

Both NO and NO_2 are produced in combustion. Nitric oxide is formed both from atmospheric nitrogen, N_2, and from nitrogen contained in some fuels. The latter source depends on the fuel composition and is not important for fuels with low nitrogen contents but is a major source of NO_x in coal combustion. Nitric oxide can be formed, however, when any fuel is burned in air because of high-temperature oxidation of N_2. To control thermal-NO_x formation, it is necessary to reduce the temperature to slow the rate of N_2 oxidation. One approach is to inject liquid water into the fuel-air mixture to reduce the flame temperature (Flagan, 1988).

A number of different technologies are applicable to the removal of nitrogen oxides originated from fuel: (e.g. overfire air, off-stoichiometric combustion, and low-NO_x burners) are only feasible in the large facilities (Flagan, 1988).

2.2.2 Site Selection

In the case of a thermal power plant, site selection is possible to choose a site where the potential environmental impacts will be under certain limits. Additionally it is always possible to make a comparative analysis between different alternatives. However, it is obvious that it is strictly not possible to make a site selection for the case of individual heating systems in an urban area. The parameters determining the relation between emissions and concentrations, in another word the self-cleansing capacity of the atmosphere, are topography and meteorology. In addition, sensitivity of the receptor environment (health of thousands of millions of people and other living organisms) is very important. In an urban area where individual domestic heating systems are used, however severe the topography and meteorology would work counterwise for self cleansing capacity of the atmosphere and consequently health of the population is endangered seriously, site selection is out of the question. In this case the only choice left to the urban population is to live under thousands of chimneys and expose themselves to the concentrated air pollution. In addition to those, depending on the choice of activity site, energy production technology, thermal efficiency, and the emission characteristics of two alternatives are very different. For a thermal power plant, emission is from a tall point source where the outlet velocity and the temperature of the emissions are very high; for individual heating systems, emission is from thousands of chimneys from almost ground level with much lower outlet velocity and the temperature. In addition, emission treatment will not be possible at all in smaller combustion systems. In short, both the emission minimization and dispersion maximization will show significant advantages in the case of a thermal power plant.

Geometrical configuration of the facility buildings at the site of choice is of significant importance within the selected site and can result in noticeable reductions on the pollutant concentrations (Kayın *et al.*, 1995) as well as the site selection itself. This can only be practically controlled in the case of thermal power plants but not possible in a residential area. For example thermal plants with dry cooling tower system cause high concentrated air pollution problems in short term by means of building downwash effect. Geometrical configuration of the stack, tower and other buildings relative to each other, considering the meteorological and topographical characteristics of the vicinity will solve the short term air pollution problems to a large extent. Suitable choice of those parameters which affects the dispersion of pollutants (e.g., stack height, exit velocity and temperature and geometrical configuration) emitted from a large energy generating facility, will reduce the short term ground level concentration in the receptor environment. In urban areas current air pollution problems are enhanced by the uncontrolled and unplanned increase of number of buildings. In addition, building downwash effect is a problem without any solution in cities because of the low stack height, low exit velocity and temperature. As a result, reducing currently observed ground level concentrations in urban areas in winter season require radical solutions.

The main parameters of interest in site selection which in turn determines the potential air quality impacts are summarized below.

2.2.2.1 Topography

Topographical characteristics (hills, valleys, flat areas and their spatial distribution) in the facility area determine the level of dispersion and transportation of the pollutants and hence where the maximum concentrations will occur. Selection of a site ensuring the maximum dispersion capacity will minimize the potential concentrations in the local scale and enable to protect susceptible receptor areas effectively.

2.2.2.2 Meteorology

Similarly, meteorological characteristics (wind direction and speed, ambient air temperature, pressure, precipitation, relative humidity, cloud and snow cover at the region and as a function of these vertical movement of air parcels in the atmosphere and mixing height) of the facility area determine the level of diffusion of pollutants in the vertical scale, transportation of pollutants in the horizontal scale and type of deposition of the pollutants (dry or wet). An appropriate site selection aiming to maximize dispersion capacity and resulting in possible minimum hourly, daily and annual average concentrations should be seeked for.

2.2.2.3 Susceptibility of the Receptor Environment

Ecosystem components (water, soil, air and their dependants including human) in the receptor environment are directly affected by any energy production activity. Impacts of the same activity will be different on different ecosystem components having different characteristics, hence a site with the least susceptible ecosystem components should be selected for a proposed activity.

Comparison can be made between the susceptibilities of different receptor environments for selecting the site of a proposed thermal power plant. However, such an approach is not possible for the current combustion systems used in urban areas for domestic heating. Decrease in number of emission sources, by means of using large facilities, will radically help to solve the air pollution problems in urban areas.

2.2.3 Legal Requirements, Auditing and Sanctions

One of the most important step to prevent potential environmental impacts is to foresee those prior to activities start and try to find ways of minimizing them (different site selection alternatives, production technologies, control technologies, cleaner fuels) or even choosing not to do alternative if the environmental impacts appear to be unacceptable. The philosophy here is to prevent pollution formation or minimize it to the extent of being acceptable, rather than seeking for solution after pollution is already created. This planning approach which can be summarized as "Foreseeing the Impacts" is named as

Environmental Impact Assessment (EIA) which is well defined in our currently effective regulations. However, in practice, while EIA procedure is valid and a must for a thermal power plant, it is not strictly applicable to the small combustion systems used in the urban areas. In general, urban development plans carefully consider parameters such as infrastructure, transportation facilities, etc., on the other hand, air pollution impacts of thousands of chimneys are generally ignored. Another crucial point in this context is that even if the EIA procedure is strictly applied for both cases (e.g. for stack gas concentration standards), auditing and giving sanctions, if required, will not be practically achievable in the case of small combustion systems.

Operation of a facility (i.e. a thermal power plant) can be ceased according to the current legislation when it is not in compliance with the standards. The same procedure can not be applied to the chimneys in an urban area in practice. At the present, certain temporary measures are applied in urban areas when the problem is encountered. In nature, these are not radical solutions, they only solve the problem for a very short period of time. For example, when the level of pollution exceeds the limits in urban areas, the stoves and the boilers are allowed to be burned between scheduled hours and for rest of the time combustion is not permitted. For a similar case, operation of a thermal power plant can be ceased, or even permission for operation is only given if the standards related to the emissions and the receptor environment are satisfied.

Legal requirements, auditing and sanctions for environmental impacts are completely applicable to a thermal power plant theoretically and practically. But these are not practically applicable in the case of small hand fired systems (stoves and boilers). Table 2.4 below summarizes applicability of air quality mitigating measures on individual domestic heating systems and thermal power plants. Additionally in Appendix C possible mitigating measures for thermoelectric projects are given in a greater detail. As can be seen from Table 2.4, both theoretical and practical applicability of mitigation measures in the case of thermoelectric power generation as opposed to the current individual domestic heating systems show outstanding advantages from the perspective of efficient air quality control.

Table 2.4 Applicability of air quality mitigating measures on individual domestic heating systems and thermal power plants

Mitigating Measures	Individual Domestic Heating Systems	Electricity use in Domestic Heating
Emission Minimization		
Better Fuel	Applicable but difficult to audit	Applicable
Better Combustion Technology	Difficult to achieve	Applicable and can easily be audited
Effluent Treatment (Control Technology)	Not Applicable	Applicable
Maximization Dispersion		
Site Selection (Topography and Meteorology)	Not Applicable	Applicable and already enforced by regulations
Facility Design and Geometrical Configuration	Not Applicable	Applicable and already realized in a few EIA studies in Turkey
Legal Control (related to the above items)		
Fuel Type and Characteristics	Applicable but difficult to audit	Applicable
Combustion Technology	Not Applicable	Applicable
Treatment System	Not Applicable	Applicable and enforced by regulations
Minimization of Impact on the Receptor Environment		
EIA	Applicable but not enforced in practice	Applicable and enforced by regulations
Permits (related to the site selection and stack gas effluents)	Not Applicable	Applicable and enforced by regulations
Monitoring (related to the stack gas effluents and ambient concentration)	Applicable but not enforced in practice	Applicable and enforced by regulations

2.3 Economical Factors

Within the context of this study, the economical factor is understood as the cost of energy production. This cost, "cost per unit energy consumed" depends on i) investment cost, ii) cost of energy production, and iii) cost of transmission losses.

2.3.1 Investment Cost

Investment cost of a combustion system may be the construction cost of a thermal power plant or cost of a stove or boiler including the cost of necessary infrastructure such as pipelines etc. as in the case of natural gas. Construction of a thermal power plant generating energy for domestic heating and price of the overall collection of individual combustion systems such as stoves or boilers, are of comparable cost despite of the common contradictory thought (see Table 6.1). The quantitative analysis and corresponding monetary comparison for Ankara case is given in Chapter 6.

In addition, there is an interesting point to note for Ankara case. Economical life of a thermal power plant is about 25 to 30 years. However, in Ankara, Çankaya, boilers have been changed four times in the last 25 years, as a result the cost of each boiler has been paid by the consumers. Earlier coal fired boilers using poor quality Turkish coal had been converted to oil fired boilers in 1970's to eliminate severe air pollution problems encountered in the city, assuming emissions would have been decreased. Following this however, in the late 1970's and early 1980's faced with the world petroleum crisis and substantial increase in prices, boilers had been once more converted, this time using imported low-sulphur coal. Finally, having seen the problem had not been solved yet, about five years ago it was decided to use natural gas for domestic heating systems.

2.3.2 Production Cost

Absolute cost of energy generation will be the sum of unit cost of the fuel, amount of the fuel combusted which is inversely proportional with the thermal efficiency of the technology used, man power, maintenance and other operational costs of the system used.

Theoretically, unit cost of the fuel used in stoves and boilers can be thought as the same with the cost of the fuel used in a thermal power plant. But the wholesale to be used in thermal power plants is much cheaper[3].

The amount of fuel to be used for unit energy production depends on the heating value of the fuel and thermal efficiency of the combustion technology. Although combustion efficiency is much lower in stoves and boilers in comparison to thermal power plants where complete combustion is achieved under controlled conditions; thermal efficiencies are lower in thermal power plants since heat energy is converted to electricity. Still however, quantitative analysis of such two alternatives result in comparable amount of fuel use (see Table 4.5 and 4.7).

Another factor of the production cost is man power. For the case of individual stoves used in the houses, payment is out of question. On the other hand, there is a payment involved for the boilers used in the buildings and the economical cost of the time lost firing the stoves can be accounted for. Operation of thermal power plants obviously requires professional staff and payments are correspondingly higher. Maintenance costs, in this context, are rather difficult to evaluate for individual heating systems. However, a simple operational and maintenance cost analysis for thermal power plants is given in Chapter 6 (see Table 6.3).

2.3.3 Transmission Losses

Transmission losses depend on the technology used for transmission and distance between the production and consumption sites. For example in our country, hydroelectric energy produced in South and Southeast Anatolia is transmitted by interconnected system to the highly populated and industrialised Western Anatolia results in about 10-15% of transmission loss. (TEK, 1993). However, this figure corresponds to the average of whole country and the loss is much lower when facilities are closer to the consumption site.

3 In 1991 price of coal sold to thermal power plants by TKİ (Turkish Coal Managements) was 10.84 $/ton, price of coal sold to residential and industrial consumption by TKİ was 30.57 $/ton (Arıoğlu, 1995).

Obviously, there is no significant transmission loss when heat energy is directly produced in stoves or boilers.

CHAPTER 3

CONTRIBUTION OF DOMESTIC HEATING ON URBAN AIR POLLUTION

In this chapter, current air quality status of Ankara is discussed. and related statistical measurement data are presented. Current air quality status of Turkish cities[1] is discussed and related statistical measurement data are presented in Appendix D. In this context, the reference point is obviously currently effective Turkish Air Quality Regulation Standards which are given in Table 3.1 below alongside with WHO standards.

Table 3.1 Current air quality standards in Turkey and WHO

Pollutants	Turkish Air Quality Standards ($\mu g/m^3$)			WHO Standards ($\mu g/m^3$)	
	LTS[1]	STS[2]	RSV[3]	LTS	STS
SO_2	150 (60)[4]	400	900	50	125
NO_2	100	300	-	-	150
PM (<10μ)	150 (60)[4]	300	60	50	120
O_3 (ppb)	110	-	240	100-200[5]	-

Sources: Official Gazette, No. 19269, 2 November 1986
WHO Air Quality Guidelines for Europe, 1987

1 Long Term Standards (maximum yearly average)
2 Short Term Standards (maximum daily average)
3 Reference Standard Value (maximum hourly)
4 Target Long Term Standard
5 1 hour mean/exceeded once per month

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1 This discussion is based on the detailed and through evaluation presented in the UÇEP Report (Tuncel, 1995).

In many countries ambient air quality standards are much stricter in comparison to Turkish Air Quality Regulations. A summary of European Ambient Air Quality Standards are presented in Appendix E which gives a clear indication of the severity of problems in Turkish cities. As it is known, SO_2 and smoke have been daily or continuously measured in Turkish cities by Ministry of Health; and these measurements have been processed and published monthly by the State Institute of Statistics since 1990. SO_2 and SPM concentrations measured in Turkish cities are given in Appendix D in detail.

3.1 Current Status in Ankara

Ankara has long been faced with severe air pollution problems during the past 30 years and both the Central Government and various Local Governments of the city developed various measures to combat this problem. During the last five years, as the domestic heating systems are converted to natural gas fired systems, a remarkable decrease in ambient concentrations of SO_2 and SPM has been achieved.

In Ankara winter season average SO_2 concentrations for the years of 1990, 1991, 1992, 1993, 1994, 1995 are given in Table D.1 as 218, 187, 130, 90, 79, 78 $\mu g/m^3$ respectively. Similarly, however the decrease trend being not as significant as SO_2, winter season average SPM concentrations for the years of 1990, 1991, 1992, 1993, 1994, 1995 are given in Table D.2 as 107, 118, 97, 108, 77, 84 $\mu g/m^3$ respectively. In Table 3.2, 3.3 and 3.4 the results of monthly air quality measurements of SO_2 and SPM in Ankara is given for the period between January 1990 and December 1995. NO and NO_2 concentrations are measured only in two stations namely Sıhhiye and Küçükesat since 1994 and monthly measurement results are shown in Table 3.5 for the period between January 1994 and December 1995. SO_2 and SPM concentrations are the averages of data obtained from eight measurement stations, namely Bahçelievler, Cebeci, Çankaya, Demetevler, İncirli, Küçükesat, Sıhhiye and Yenidoğan. Most of these stations are located at the sites where natural gas conversion has been completed up to a great extent. On the outer reaches of the city, however, if measurements had been possible, much higher results could be expected as most of the population still relies on coal fired systems. Concentrations measured in Bahçelievler, Çankaya and Küçükesat where natural gas systems are in great majority, have a significant effect on calculating lower averages.

Another important point regarding recent measurement results of Ankara (see Table 3.5) is NO_x concentrations. Although there has not been enough amount of data accumulated to comment on the trend, it is seen that both LTS and STS have been exceeded a few times in winter months.

Table 3.6 and Table 3.7 shows the winter/summer concentration ratios of SO_2 and SPM for 1990-1995 regarding each of these stations. As can be seen from the tables, winter/summer concentration ratio of SO_2 is around 3.5 while that of SPM is around 2.0 for 1990-1992 and 2.5 for 1993-1995. There is a decreasing trend in winter/summer concentration ratio of SO_2 in Bahçelievler, Çankaya and Küçükesat where natural gas is used for domestic heating.

Table 3.2 Summary of SO_2 and SPM measurements in Ankara (1990-1991)

Month	1990						1991					
	SO_2 ($\mu g/m^3$)			PM ($\mu g/m^3$)			SO_2 ($\mu g/m^3$)			PM ($\mu g/m^3$)		
	Ave[1]	Min[2]	Max[3]	Ave	Min	Max	Ave[1]	Min[2]	Max[3]	Ave	Min	Max
January	378	78	1313	237	48	747	293	82	666	131	29	342
February	293	72	759	130	29	394	236	71	679	94	10	269
March	242	51	655	130	35	274	148	37	316	72	28	156
April	120	15	285	78	21	207	79	19	159	51	4	128
May	78	7	246	65	14	149	35	8	79	42	6	115
June	33	5	70	51	17	112	34	10	109	54	8	107
July	28	9	87	44	19	95	36	6	94	52	9	118
August	40	18	89	48	20	108	31	7	90	55	5	138
September	49	8	124	67	30	243	51	6	135	79	7	202
October	106	16	422	89	30	243	63	13	111	88	31	166
November	249	26	763	139	30	361	136	5	375	152	22	349
December	256	24	566	113	30	316	180	31	481	96	10	420
Annual Average	170			103			125			83		

[1] Monthly average
[2] Daily average minimum
[3] Daily average maximum

Table 3.3 Summary of SO_2 and SPM measurements in Ankara (1992-1993)

Month	1992						1993					
	SO_2 ($\mu g/m^3$)			PM ($\mu g/m^3$)			SO_2 ($\mu g/m^3$)			PM ($\mu g/m^3$)		
	Ave[1]	Min[2]	Max[3]	Ave	Min	Max	Ave[1]	Min[2]	Max[3]	Ave	Min	Max
January	115	7	323	152	26	530	206	44	582	164	16	572
February	112	19	421	115	18	414	113	16	286	73	8	218
March	91	18	272	79	25	198	84	6	179	65	7	213
April	27	6	81	68	20	167	43	8	119	47	12	122
May	..	..	..	..	..	..	26	10	69	41	13	118
June	..	..	..	..	..	..	21	1	75	40	6	111
July	..	..	..	..	..	..	19	4	91	35	7	134
August	..	..	..	..	..	..	19	6	62	32	12	70
September	..	..	..	..	..	..	45	14	108	59	16	126
October	..	..	..	..	..	..	43	7	150	89	17	318
November	..	..	..	..	..	..	76	7	206	128	8	451
December	104	6	358	78	12	321	104	18	330	142	17	507
Annual Average	..			..			72			80		

[1] Monthly average
[2] Daily average minimum
[3] Daily average maximum

Table 3.4 Summary of SO_2 and SPM measurements in Ankara (1994-1995)

Month	1994						1995					
	SO_2 (µg/m^3)			PM (µg/m^3)			SO_2 (µg/m^3)			PM (µg/m^3)		
	Ave[1]	Min[2]	Max[3]	Ave	Min	Max	Ave[1]	Min[2]	Max[3]	Ave	Min	Max
January	115	7	323	122	8	370	102	16	327	77	11	254
February	112	19	421	95	24	226	124	38	291	89	24	248
March	91	18	272	71	17	303	55	12	219	58	16	194
April	27	6	81	48	10	174	41	5	111	40	6	87
May	19	6	50	34	13	81	22	4	70	33	6	73
June	22	7	57	22	4	62	20	4	59	32	10	81
July	21	7	53	24	3	59	19	4	69	30	7	72
August	23	5	82	27	9	66	23	5	65	30	7	80
September	31	9	80	47	7	106	23	4	68	41	4	123
October	37	8	91	56	13	195	82	3	522	68	15	221
November	60	3	240	85	13	324	85	9	310	108	17	350
December	104	6	358	96	13	282	93	16	479	93	19	429
Annual Average	170			103			125			83		

[1] Monthly average
[2] Daily average minimum
[3] Daily average maximum

Table 3.5 Summary of NO and NO_2 measurements in Ankara (1994-1995)

Month	1994						1995					
	NO (μg/m³)			NO_2 (μg/m³)			NO (μg/m³)			NO_2 (μg/m³)		
	Ave[1]	Min[2]	Max[3]	Ave	Min	Max	Ave[1]	Min[2]	Max[3]	Ave	Min	Max
January	124	28	372	60	13	125	59	3	197	48	22	89
February	77	17	173	55	13	103	79	13	158	63	42	121
March	75	34	131	43	16	84	45	4	121	71	22	175
April	97	15	284	67	9	222	42	21	82	53	36	93
May	110	18	337	87	20	299	23	9	51	38	17	59
June	37	6	193	30	11	148	25	10	44	36	21	56
July	8	5	15	13	3	21	16	8	35	31	18	71
August	17	4	63	39	21	66	21	6	59	26	11	42
September	46	8	111	49	33	72	44	9	125	33	16	87
October	72	16	154	48	10	84	86	34	179	62	43	104
November	89	23	231	43	16	83	85	15	188	59	23	93
December	82	11	224	57	35	98	83	11	224	57	35	98
Annual Average	70			49			51			48		

[1] Monthly average
[2] Daily average minimum
[3] Daily average maximum

Table 3.6 SO_2 Winter /Summer concentration ratios in Ankara ($\mu g/m^3$)

Measurement Stations	90-91 Win/Sum	91-92 Win/Sum	92-93 Win/Sum	93-94 Win/Sum	94-95 Win/Sum	95-96 Win/Sum
Bahçelievler	3.6	5.4	..	2.6	2.7	2.2
Cebeci	3.1	4.9	..	2.5	..	2.5
Çankaya	3.7	5.3	..	3.2	2.7	1.7
Demetevler	..	..	..	4.1	4.2	5.4
İncirli	..	..	..	..	5.6	4.8
Küçükesat	..	..	..	2.9	2.4	2.7
Sıhhiye	3.3	3.7	..	2.7	2.8	3.4
Yenidoğan	3.5	4.2	..	3.7	3.4	3.2

Table 3.7 SPM Winter/Summer concentration ratios in Ankara ($\mu g/m^3$)

Measurement Stations	90-91 Win/Sum	91-92 Win/Sum	92-93 Win/Sum	93-94 Win/Sum	94-95 Win/Sum	95-96 Win/Sum
Bahçelievler	2.2	1.9	..	2.5	2.2	2.0
Cebeci	2.0	2.1	..	2.8	..	2.6
Çankaya	1.6	3.7	..	2.2	2.2	2.8
Demetevler	..	..	..	3.2	2.8	3.6
İncirli	..	..	..	..	3.0	2.5
Küçükesat	..	..	..	2.2	1.5	1.9
Sıhhiye	1.9	1.8	..	2.2	1.9	1.7
Yenidoğan	1.7	1.8	..	2.6	3.1	2.6

3.2 The Causes

Energy demand for domestic heating has been rising in urban areas in Turkey proportional with the increase in population and standard of living. This demand has been mostly met by producing heat energy by the coal fired stoves or boilers (i.e. individual heating systems) which result in high air pollution levels in our cities to an extent that the health of the people have been under risk as the data outlined in Appendix D clearly indicates (see Section 3.3). In most of the Turkish cities the main reason of the pollution is domestic heating and it is followed by the industry and/or transportation. Summary of results of a recent emission inventory conducted for Ankara (Atımtay, 1993) is presented in Appendix F. According to this study, domestic heating is the main cause of pollution in Ankara regarding CO, H_xC_y, SO_2 and SPM, except NO_x for which the primary source is traffic.

The causes given above are all related with the use of fossil fuels, or in other words internal or external combustion emissions. However, ambient air quality is judged in terms of concentrations which in turn a function of emissions, but also how they are released and how they are dispersed. In this context, the cause of urban air quality problems can be grouped into three as i) the fuel and combustion system, ii) multiple sources with no control and iii) urban meteorology.

3.2.1 The Fuel and the Combustion System

The fuel and the combustion system used in the domestic heating is of significant importance for potential air quality impacts as discussed previously in parts 2.2.1.1 and 2.2.1.2. Obviously, use of cleaner fuels with higher heating value and combustion systems with higher combustion and thermal efficiency will result in lower emissions per unit heat energy produced for domestic heating. However, in the Turkish case, switch to natural gas meant a higher foreign dependency of country's economy (see Section 2.2.1.1) and switch to imported coal proved to be not very efficient as the use of Turkish coal still continues illegally in various sites of Ankara and İstanbul. Additionally, attempts for individual heating systems with better combustion characteristics resulting in the theoretical emission values is very questionable (see Section 2.2.1.2).

3.2.2 Multiple Sources with no Control

In urban areas where population is dense, individuals live under thousands or hundreds of thousands of stacks with direct contact to pollutant emissions. These stacks are generally short, discharging emissions having low exit velocities and low exit temperatures and consequently having lower dispersion capabilities .

It is practically not feasible to control emissions originating from thousands of point sources. The reason for this (see also Table 2.4) can be summarized in three steps.

- Planning/foreseeing and commitments regarding emissions originated from domestic heating systems either does not exist, or is not sufficient, or practically not applicable and not inspectable. In case of violating stack gas or ambient air quality standards, cease of activities or not to do alternative in not possible.

- Technical mitigation measures in order to increase dispersion potential of pollutants (i.e. increase in stack heights, emission exit velocity, exit temperature, and most important of all flue gas treatment) are not practically applicable.
- Site selection which enables to chose a meteorological and topographical setting to maximise dispersion and a receptor environment which is least susceptible is not possible at all in case of urban areas with individual heating systems.

In this regard, urban meteorology is of significant importance on the air quality problems observed in many cities.

3.2.3 Urban Meteorology

It has been recognized for many decades that the presence of an urbanized surface produces a variety of changes in the climate of a city. These departures from the preurban climate of the place constitute the "urban effect on climate" which is usually estimated by obtaining measures of differences in atmospheric variables between the urban area and some typical, contemporary, nearby rural area. In general, the deviations of concern in the atmospheric variables have a negative effect on the dispersion potential of pollutants in the urban area. Some of the most important parameters that influence pollution dispersion adversely in urban areas are summarized below.

Heat Emissions: Not only pollutants but significant amount of heat is emitted into the urban atmosphere by hot gas emissions and heated buildings. Additionally, concrete surfaces conduct sun's energy three times faster than soil surfaces. As a result in an urban area during daytime more heat energy is absorbed compared to the rural areas. In contrast, during nightime more radiational cooling is observed in rural areas. The heat energy is reradiated into the atmosphere and a dramatic cooling affect occurs at the surface. Therefore, a cooler surface and warmer overlying layers can be observed in the atmosphere; or the rate of temperature decrease with increasing height can be lower than neutral, indicating stable atmospheric conditions. Especially in winter months at night a heat island can easily form severely restricting the vertical dispersion potential where pollutants are trapped near the surface and can not penetrate through the inversion. This is (increase in temperature with increasing height) very common in urban areas which results in higher ambient air pollution levels and in some cases episodic conditions.

Average wind speed: Higher topographical features surrounding the cities generally result in blocking the strong winds. As a result, stagnant conditions are more common in cities compared to the rural areas, average wind speeds are lower and frequency of strong winds are smaller. These will directly imply a weaker potential for horizontal transport of pollutants and indirectly a lower potential for atmospheric instability and hence vertical transport. Even if there is no significantly high surrounding topographical features around the city, the tall buildings within the city can be effective as windbreaks. In general, the average wind speeds observed in cities are 25% lower compared to rural areas (Weisberg, 1976).

Building Downwash: Beside affecting the general circulation pattern in cities, tall buildings have another adverse impact on urban air quality. Emission plumes discharged from not-so-tall-stacks will be captured by the aerodynamic wakes and eddies created by the adjacent buildings, resulting in building downwash effect and very high localized concentrations or hot spots (Huber and Synder, 1976, 1982).

Precipitation and Fog: Despite the fact that mean relative humidity is 6% lower in cities because the rainwater is collected with drainage systems hence causing less evaporation, in rural areas 10% more precipitation is observed. Additionally, fog events are 30% more in summer and 100% more in winter time. The reason for that is thought to be the higher SPM in the atmosphere serving as cloud condensation nucleides (CCNs). In the urban atmosphere, therefore, when atmosphere is cleansing itself through condensation and precipitation, fog events in which chemical conversions are very fast, will cause a direct contact between acidic species and human beings and other living species (Weisberg, 1976).

3.3 Health and Economic Benefits of Air Pollution Abatement

An average 15 million residents of the major cities (i.e. Ankara, İstanbul, İzmir, Bursa, Kayseri, Erzurum, Sivas,) in Turkey have been exposed to SPM and SO_2 levels above the WHO standards in the 1990-1993 period. An assessment of health effects due to SPM and exposure to SO_2 suggests that if annual SPM and SO_2 were reduced to the WHO standards, this could have brought a reduction of 5.94 and 5.48 thousand hospital admissions for respiratory diseases, 121.4 and 112.1 thousand emergency room visits, 8.26 and 6.85 million restricted activity days, 57 and 73 thousand cases of low respiratory symptom of children 0-12 years age, in 1990 and 1993 respectively. The estimated annual economic value of avoiding these effects is nearly 0.12% and 0.08% of 1990 and 1993 GNPs respectively. Furthermore, the results show that by attaining WHO air pollution standards 3.31 and 3.06 thousand lives may have been saved in 1990 and 1993 respectively (Zaim, 1996).

3.4 Conclusions

In order to minimize air pollution problems encountered in our cities, as a medium term target, industrial activities should be moved out of the urban areas. For traffic originated air pollution however, the only main solution is extensive use of public transportation. For air emissions generated from domestic heating, although the alternatives are various, the most radical solution appears to be encouraging electricity use in domestic heating. Among the factors determining the level of air pollution problems in urban areas, only the fuel and type of combustion systems can be decided on. However, as long as the extensive use individual boilers and stoves are continued there exists no site selection alternatives (i.e. meteorology and topography will work counterwise to eliminate problems). In addition combustion and thermal efficiencies of heating systems are bound to be not very high. Moreover, with a massive 35 million population increase expected in our cities in the next 20 years, the efforts to sustain the current emission levels with the existing individual systems will no doubt to be insufficient. Even if electricity use for domestic heating can not be a short term target for the whole urban population of the country, the efforts should start from now on in order to investigate feasibility of this alternative. Therefore in the following chapters of this thesis, a comprehensive air quality and a brief cost analysis of different domestic heating alternatives based on electricity use are studied in the case of city of Ankara.

CHAPTER 4

REQUIREMENT OF ENERGY FOR DOMESTIC HEATING IN ANKARA

4.1 Energy Production for Domestic Heating in Ankara

In order to calculate the energy required for domestic heating for the winter season of 1991-1992 in Ankara, the previous studies carried out in Gazi University have been used. Heat energy requirement of Ankara (for 31 districts in the city center) has been evaluated by using the amount of fuel consumed, fuel characteristics and combustion system characteristics. Fuel characteristics used for domestic heating in Ankara are given in Table 4.1. Fuel types used for domestic heating are mainly domestic lignite, imported hard coal, natural gas and fuel oil.

Table 4.1 Characteristics of fossil fuels used in domestic heating in Ankara

Fuel Type	Sulphur Content %	Lower Heating Value[1] kcal/kg	Fuel Price[2,3] $/ton
Domestic Lignite (SOMA)	1.0	4000	65
Imported Hard Coal	0.3-0.1	6000	173
Natural Gas	-	8100	285
Fuel Oil	0.9	9800	278

Source: Durmaz *et al.*, 1993
[1] in kcal/Nm^3 for Natural Gas
[2] in $/1000 Nm^3 for Natural Gas
[3] Prices are for June 1992

Combustion systems and their efficiencies are summarized in Table 4.2. Emission factors of stoves taken from Durmaz *et al.*, (1993) which are presented in Table 4.2 are lower than that of USEPA emission factors summarized in Table 4.3. On the other hand, emission factors for boilers are higher than that of USEPA. There is a is a significant difference between the emission factors evaluated by Durmaz *et al.*, (1993) and USEPA. This might have been due to the very low efficiencies and unfavoured conditions of current boilers used for domestic heating in Ankara.

Fuel consumption and heat production in districts of Ankara for winter 1991-1992 are given in Table 4.4. For each district, calculations have been accounted for using the number of buildings in regular and irregular settlements, fuel consumption by type of the combustion system and the emission characteristics of current combustion systems. Therefore, the energy requirement in each district and the total cumulative energy for domestic heating for city of Ankara for 1991-1992 has been calculated and the results are summarized in Table 4.5.

Table 4.2 Characteristics of commonly used domestic heating systems in Ankara

Characteristics/Type of Combustion Systems		STOVES			BOILERS			
		Imported Hard Coal	Soma Lignite	Natural Gas	Imported Hard Coal	Soma Lignite	Fuel-Oil	Natural Gas
Thermal Efficiency (%)		50	50	81	62	55	81	85
Price of Combustion Equipment (US$)		72	87	1,670	21,643	21,643	17,315	10,519
Specific Emissions (g/kg)[1]	SO_2	4	12	0.017	4.6	32.2	15.3	0.017
	NO_2	2.3	2.1	1.58	1.63	2	4.5	2
	PM	2	3	0.138	1.45	28.8	2.82	0.28

Source: Durmaz *et al.*, 1993 [1] Emission factor for natural gas is in g/Nm^3

Table 4.3 Emission factors for hand fired combustion systems

Characteristics/Type of Combustion Systems		STOVES			BOILERS			
		Imported Hard Coal	Soma Lignite	Natural Gas	Imported Hard Coal	Soma Lignite	Fuel-Oil	Natural Gas
Specific Emissions (g/kg)[1]	SO_2	5.7	19	0.0096	5.7	19	15.5	0.0096
	NO_2	1.5	1.5	1.92	3	3	2.3	1.92
	PM	10	10-7.5	0.16	0.68	2.04	0.31	0.16

Source: USEPA, 1977 [1] Emission factors for natural gas is in g/Nm^3 and for fuel-oil g/liter

Table 4.4 Calculated energy production for domestic heating in districts of Ankara for winter 1991-1992

DISTRICTS		Number of Buildings	Number of Dwellings	Fuel Consumption (Tonnes/year for Hard Coal and Fuel Oil and $10^3 Nm^3$/year for Natural Gas)					Energy Produced by Different Heating Systems (10^6 kWh/year)					Total Heat Energy Produced
				Stoves		Boilers			Stoves		Boilers			10^6 kWh/year
				Hard Coal	Natural Gas	Fuel-Oil	Hard Coal	Natural Gas	Hard Coal	Natural Gas	Fuel-Oil	Hard Coal	Natural Gas	
Akdere	Reg.[1]	49	585	340	-	161	303	-	2.16	-	0.76	1.63	-	4.55
	Irreg.[2]	14028	23848	23343	-	-	-	-	148.28	-	-	-	-	148.28
Aktepe	Reg.	161	1657	1781	-	329	614	-	11.31	-	1.55	3.30	-	16.16
	Irreg.	9919	16863	16506	-	-	-	-	104.85	-	-	-	-	104.85
Aşağı Eğlence	Reg.	984	11268	7971	-	538	9493	-	50.63	-	2.54	51.04	-	104.21
	Irreg.	-	-	-	-	-	-	-	-	-	-	-	-	-
Aydınlık	Reg.	2355	17654	18473	9171	-	6833	17395	117.34	13.37	-	36.74	25.36	192.81
	Irreg.	-	-	-	-	-	-	-	-	-	-	-	-	-
Ayrancı	Reg.	1816	22412	1442	830	10019	22447	29708	9.16	1.21	47.27	120.69	43.31	221.64
	Irreg.	-	-	-	-	-	-	-	-	-	-	-	-	-
Bahçelievler	Reg.	2883	23537	5308	2147	6770	30919	16483	33.72	3.13	31.94	166.24	24.03	259.06
	Irreg.	-	-	-	-	-	-	-	-	-	-	-	-	-
Balgat	Reg.	1654	7333	11291	96	998	1782	1777	71.72	0.14	4.71	9.58	2.59	88.74
	Irreg.	-	-	-	-	-	-	-	-	-	-	-	-	-
Beştepe Esentepe	Reg.	558	2205	3046	844	-	136	3087	19.35	1.23	-	0.73	4.50	25.81
	Irreg.	845	1436	1406	-	-	-	-	8.93	-	-	-	-	8.93
Cebeci	Reg.	4293	36444	30257	12594	9542	25863	19103	192.20	18.36	45.02	139.06	27.85	422.49
	Irreg.	-	-	-	-	-	-	-	-	-	-	-	-	-
Çankaya	Reg.	2446	16605	2434	3574	21066	30076	36560	15.46	5.21	99.39	161.71	53.30	335.07
	Irreg.	8536	14511	14205	-	-	-	-	90.23	-	-	-	-	90.23
Çukurambar	Reg.	364	1031	1828	-	-	145	-	11.61	-	-	0.78	-	12.39
	Irreg.	3461	5884	5760	-	-	-	-	36.59	-	-	-	-	36.59

1 Regular settlement areas were constructed according to the regional plan.

2 Irregular settlement areas are generally located at the outskirts and on the hills, they have no regional construction plans and infrastructure and utility services are quite poor. The buildings in these regions are small and have one or two stories.

Table 4.4 Calculated energy production for domestic heating in districts of Ankara for winter 1991-1992 (continued)

DISTRICTS		Number of Buildings	Number of Dwellings	Fuel Consumption (Tonnes/year for Hard Coal and Fuel Oil and 10^3 Nm^3/year for Natural Gas)					Energy Produced by Different Heating Systems (10^6 kWh/year)					Total Heat Energy Produced
				Stoves		Boilers			Stoves		Boilers			10^6 kWh/year
				Hard Coal	Natural Gas	Fuel-Oil	Hard Coal	Natural Gas	Hard Coal	Natural Gas	Fuel-Oil	Hard Coal	Natural Gas	
Demetevler	Reg.	1603	25597	10563	-	6706	12510	-	67.10	-	31.64	67.26	-	166.00
	Irreg.	605	1029	1008	-	-	-	-	6.40	-	-	-	-	6.40
Devlet Mah.	Reg.	17	334	238	185	-	17	707	1.51	0.27	-	0.09	1.03	2.90
	Irreg.	321	546	534	-	-	-	-	3.39	-	-	-	-	3.39
Dikmen	Reg.	1248	9268	10099	-	4917	9165	-	65.15	-	23.20	49.28	-	136.63
	Irreg.	9622	16357	16010	-	-	-	-	101.70	-	-	-	-	101.70
Esat	Reg.	2272	24374	2199	3231	19044	27182	33021	13.97	4.71	89.85	146.15	48.14	302.82
Kavaklıdere	Irreg.	-	-	-	-	-	-	-	-	-	-	-	-	-
Etlik	Reg.	4850	30182	27278	576	1626	32372	1749	173.28	0.84	7.67	174.06	2.55	358.40
	Irreg.	3797	6455	6319	-	-	-	-	40.14	-	-	-	-	40.14
Gazi Mah.	Reg.	989	5741	7563	1468	-	-	5158	48.04	2.14	-	-	7.52	57.70
	Irreg.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hasköy	Reg.	373	2170	2613	-	608	1136	-	16.60	-	2.87	6.11	-	25.58
	Irreg.	9037	15363	15037	-	-	-	-	95.52	-	-	-	-	95.52
İncirli	Reg.	299	2916	2897	-	195	3452	-	18.40	-	0.92	18.56	-	37.88
	Irreg.	10794	18349	17961	-	-	-	-	114.09	*	-	-	-	114.09
Karşıyaka	Reg.	568	4145	4987	-	1297	2418	-	31.68	*	6.12	13.00	-	50.80
	Irreg.	15586	26496	25935	-	-	-	-	164.74	-	-	-	-	164.74
Keçiören	Reg.	1401	20005	14030	-	947	16711	-	89.12	-	4.47	89.85	-	183.44
	Irreg.	11075	18827	18428	-	-	-	-	117.06	-	-	-	-	117.06
Maltepe	Reg.	1396	13269	2635	1941	9214	25642	16991	16.74	2.83	43.47	137.87	24.77	225.68
	Irreg.	-	-	-	-	-	-	-	-	-	-	-	-	-
Mamak	Reg.	202	2181	1601	-	831	1553	-	10.17	-	3.92	8.35	-	22.44
Gülveren	Irreg.	11784	20033	19609	-	-	-	-	124.56	-	-	-	-	124.56
Saimekadın	Reg.	267	1944	1867	-	420	783	-	11.86	-	1.98	4.21	-	18.05
	Irreg.	11889	20212	19784	-	-	-	-	125.67	-	-	-	-	125.67

Table 4.4 Calculated energy production for domestic heating in districts of Ankara for winter 1991-1992 (continued)

DISTRICTS		Number of Buildings	Number of Dwellings	Fuel Consumption (Tonnes/year for Hard Coal and Fuel Oil and $10^3 Nm^3$/year for Natural Gas)					Energy Produced by Different Heating Systems (10^6 kWh/year)					Total Heat Energy Produced
				Stoves		Boilers			Stoves		Boilers			10^6 kWh/year
				Hard Coal	Natural Gas	Fuel-Oil	Hard Coal	Natural Gas	Hard Coal	Natural Gas	Fuel-Oil	Hard Coal	Natural Gas	
Seyran	Reg.	506	4664	1677	1173	464	4525	1571	10.65	1.71	2.19	24.33	2.29	41.17
	Irreg.	5745	9767	9561	-	-	-	-	60.73	-	-	-	-	60.73
Siteler	Reg.	347	6251	17224	-	577	1071	-	109.41	-	2.72	5.76	-	117.89
	Irreg.	16419	27913	27323	-	-	-	-	173.56	-	-	-	-	173.56
Telsizler	Reg.	447	6470	759	158	2794	5342	576	4.82	0.23	13.18	28.72	0.84	47.79
	Irreg.	2241	3809	3728	-	-	-	-	23.68	-	-	-	-	23.68
Ulus	Reg.	5216	20092	21451	5241	51160	22778	20029	136.26	7.64	241.37	122.47	29.20	536.94
Altındağ	Irreg.	15662	26626	26062	-	-	-	-	165.55	-	-	-	-	165.55
Varlık	Reg.	1473	7873	7815	672	-	1092	5954	49.64	0.98	-	5.87	8.68	65.17
	Irreg.	-	-	-	-	-	-	-	-	-	-	-	-	-
Yenimahhale	Reg.	3888	14374	14238	4760	216	10066	8547	90.44	6.94	1.02	54.12	12.46	164.98
	Irreg.	-	-	-	-	-	-	-	-	-	-	-	-	-
Yenişehir	Reg.	1901	28001	1965	864	43029	25300	12059	12.48	1.26	203.01	136.03	17.58	370.36
	Irreg.	-	-	-	-	-	-	-	-	-	-	-	-	-
TOTAL	Reg.	46826	370582	237870	49525	193468	331726	230475	1510.98	72.20	912.78	1783.59	336.00	4615.55
ANKARA	Irreg.	161366	274324	268519	-	-	-	-	1705.67	-	-	-	-	1705.67
	Total	208192	644906	506389	49525	193468	331726	230475	3216.65	72.20	912.78	1783.59	336.00	**6321.22**

Table 4.5 Summary of fuel consumption and heat energy production for domestic heating in Ankara for winter 1991-1992

Number of Buildings			208,192
Equivalent Number of Dwellings			644,906
Fuel Consumption	Stoves	**Hard Coal** (tonnes/year)	506,389
		Natural Gas (10^3 Nm^3/year)	49,525
	Boilers	**Fuel-Oil** (tonnes/year)	193,468
		Hard Coal (tonnes/year)	331,726
		Natural Gas (10^3 Nm^3/year)	230,475
Heat Produced by Different Heating Systems (10^6 kWh/year)	Stoves	**Hard Coal** (10^6 kWh/year)	3,216.65
		Natural Gas (10^6 kWh/year)	72.20
	Boilers	**Fuel Oil** (10^6 kWh/year)	912.78
		Hard Coal (10^6 kWh/year)	1,783.59
		Natural Gas (10^6 kWh/year)	336.00
Total Heat Energy Produced (10^6 kWh/year)			**6,321.22**
Total Heat Energy Produced (10^6 kcal/year)			**5,435,270.851**
Total Heat Energy Produced (Toe/year)			**543,527.085**

4.2 Electricity Use Alternative for Domestic Heating in Ankara

Since the aim of this study is mainly to compare air quality effects of the current domestic heating systems with the electricity use alternative, required electricity generating capacity of a thermal power plant producing the same amount of energy as the current domestic heating systems is calculated. Two types of power plants considered in this study are conventional coal fired thermal power plant (CTPP) and natural gas fired combined cycle power plant (NGCC). Conventional coal fired thermal power plant technology is chosen because of its wide use in Turkey which enables domestic lignite use. The second alternative is taken into consideration because of its high combustion efficiency with lower emission characteristics and due to the fact that there is an increasing trend toward the natural gas use in the current policy objectives of the Ministry of Energy and Natural Resources.

As the generating capacities of the power plants are calculated, transmission losses are also taken into consideration. Loss in the transmission lines is taken as 5%. This value is much lower compared to the average loss in the Turkish transmission lines which is 12%. However, the existing length of the transmission lines is very long in Turkey. Most of the electricity energy is generated in the Southeastern part of the Anatolia and transmitted to the İstanbul or other provinces located at the Western part of Turkey which increases the overall loss considerably. In this study, hypothetical thermal power plants are located closer to the consumption location. Hence the length of the transmission lines are much shorter and consequently the transmission loss will be much less compared to the country's average.

Overall electricity energy production requirement in order to meet domestic heating needs for the city of Ankara is calculated and results are shown in Table 4.6. For the two different choice of thermal power plant technology, amount of fuel to be used and required capacities are presented in Table 4.7 taking into consideration thermal efficiencies of these systems which are conveniently taken from in-use examples.

Table 4.6 Summary table of parameters used in power plant calculations

Required Heat Energy for Domestic Heating, 1991-1992	$6{,}321.22\times10^{6}$ kWh/year (see Table 4.5)
Energy Loss in Transmission Lines	5%
Energy has to be Produced in CTPP	$6{,}653.92\times10^{6}$ kWh/year
Lower Heating Value of Lignite (Soma Lignite)	4,000 kcal/kg

Table 4.7 Fuel consumption and generating capacity for different alternatives

1. Existing System		
Amount of Fuel Used	Hard Coal	838,115,000 kg/year
	Fuel-Oil	193,468,000 kg/year
	Natural gas	280,000,000 Nm³
Amount of Emissions	SO_2	6,516 tonnes/year
	NO_x	2,843 tonnes/year
	SPM	2,111 tonnes/year
2. Conventional Coal Fired Thermal Power Plants		
Efficiency		35%
Amount of Fuel Used		$4{,}086.68\times10^{6}$ kg/year
$\frac{6{,}653.92\times10^{6}\,kWh/year\times859.8452278\,kcal/kWh}{4{,}000\,kcal/kg\times0.35}=4{,}086.68\times10^{6}\,kg/year$		
Capacity of the Power Plant		660 MW
$\frac{4{,}086.68\times10^{6}\,kg/year\times20\,years\times4{,}000\,kcal/kg}{500\times10^{9}\,(FixedValue/1MW)}=654\rightarrow660\,MW$		
Amount of Emissions	SO_2	23,566 tonnes/year
	NO_x	8,003 tonnes/year
	SPM	150,400 tonnes/year
3. Natural Gas Fired Combined Cycle Power Plant		
Efficiency		53%
Amount of Fuel Used		$1{,}332.72\times10^{6}$ Nm³/year
$\frac{6{,}653.92\times10^{6}\,kWh/year\times859.8452278\,kcal/kWh}{8{,}100\,kcal/Nm^{3}\times0.53}=1{,}332.72\times10^{6}\,Nm^{3}/year$		
Capacity of the Power Plant		450 MW
$\frac{1{,}332.72\times10^{6}\,Nm^{3}/year\times20\,years\times8{,}100\,kcal/Nm^{3}}{500\times10^{9}\,(FixedValue/1MW)}=432\rightarrow450\,MW$		
Amount of Emissions	SO_2	142 tonnes/year
	NO_x	6,108 tonnes/year
	SPM	34 tonnes/year

CHAPTER 5

AIR QUALITY IMPACT ANALYSIS OF ELECTRICITY USE IN DOMESTIC HEATING IN ANKARA

In order to evaluate air quality effects of a power plant generating the required amount of energy for domestic heating in Ankara for the year 1991-1992, a series of model simulations have been undertaken. In this study The Industrial Source Complex-Short Term (ISCST) model has been used for the estimation of hourly, daily and yearly ground level concentrations of SO_2, NO_x and SPM. For this purpose, six different sites and two different thermal power plant technology alternatives at each site have been investigated.

5.1 Review of Air Quality Models

An air quality model is a mathematical description of the processes in the atmosphere which govern the fate of pollutants released from a source. The processes include; the dilution of the pollutants at the point of release, the movement or transport of the pollutant away from the source, the dispersion about the path the pollutant travels, the chemical reactions undergone by the pollutant during transport, and the removal of the pollutant from the atmosphere.

Suitability of an air quality model assessing potential impacts depends upon several factors (USEPA, 1987). These include: i) the meteorological and topographic characteristics and complexities of the facility area, ii) the level of detail and accuracy needed for the analysis, iii) the technical competence of those undertaking air quality simulation modeling, iv) the resources available, v) the detail and accuracy of the database (i.e., emissions inventory, ambient air quality data, and meteorological data). In general, air quality models can be grouped into four classes: statistical (or empirical), physical, numerical (or comprehensive) and Gaussian.

***Statistical or Empirical Models*:** Generally applied to situations when scientific understanding of physical or chemical processes are not sufficient or data bases required for the Gaussian or numerical modeling are not available.

***Physical Models*:** They involve the use of wind tunnel or other fluid modeling facilities. Physical modeling is generally useful for complex flow situations, such as building, terrain or stack downwash conditions, plume impact on elevated terrain, diffusion in an urban environment, or diffusion in complex terrain. If physical modeling is available and its applicability demonstrated, it may be the best technique (USEPA, 1987).

***Numerical or Comprehensive Models*:** Generally appropriate for area source urban and regional scale applications. However they require extensive input data bases, computational resources and expert modelers.

***Gaussian models*:** Gaussian models are the most widely used method to estimate the impacts of nonreactive pollutants. The Gaussian model assumes that continuously released nonreactive material is transported in a direction opposite to the wind direction and time-averaged spreading of the material will result in cross-sections of pollutant concentrations horizontally and vertically through the pollutant plume that have normal distribution (Schulze, 1990). Gaussian models are generally employed in coal fired power plant applications.

Extensive theoretical and experimental investigations of atmospheric diffusion have shown that the concentration of a substance at the receptor downwind from a source can generally be represented by a Gaussian function given below

$$X_{(x,y,z)} = \frac{Q}{2\pi v \sigma_y \sigma_z} e^{-1/2\left[(y/\sigma_y)^2 + (z/\sigma_z)^2\right]}$$

where;

X= concentration at some point in the x, y, z coordinate space (kg/m^3),

σ_y and σ_z = standard deviation of the dispersion in the y and z directions (m),

Q= Emissions (kg/sec),

v = average wind speed (m/sec.).

The standard deviations are measures of how much the plume spreads. If y and z are large, and the concentration is low as well. The opposite is true if the spread is small. And the dispersion is dependent on both atmospheric stability and the distance from the sources (Vesilind, 1980).

5.2 Description of the Simulation Model

The Industrial Source Complex-Short Term (ISCST) model is considered to be the most advanced computer model that can estimate hourly, daily and annual average ground level concentration (GLC) values under varying conditions of real-time meteorological data. The ISCST model combines and enhances various dispersion model algorithms to account for pollutant sources such as isolated stacks and fugitive emissions. In assessing the air quality impact of emissions from a wide variety of sources associated with an industrial source complex, the model also considers wake effects, gravitational settling and dry deposition. Point, area or volume sources can be modeled with ISCST. The model has an option to consider the effects of aerodynamic wakes and eddies produced by on and off-site buildings and structures.

The grid system used by ISCST can be either polar or cartesian. Discrete receptor points can also be included. Pasquill stability classes are used in dispersion calculations. Additionally, the ISCST model has a terrain correction option. For SPM, the ISCST incorporates size distribution data including terminal settling velocity and surface reflection coefficient of each class. The model requires four types of input data.

- Meteorological data include hourly data for wind direction and speed, ambient air temperature, pressure, cloud cover, snow cover, Pasquill stability class, mixing height, wind profile exponent (optional), and vertical potential temperature gradient (optional).
- Source data require source location with respect to a user defined origin, source elevation, source diameter, exit velocity, exit temperature and pollution emission rate.
- Receptor data include coordinates and elevations of selected grid points and receptors.

Program control parameters include user-selected run control options to select between 30 different alternatives.

5.3 Input Data Used

Model simulations have been made for SO_2, NO_x and SPM emissions generated from two different power plant alternatives located at six different sites set in and around Ankara, namely Keçiören, Esenboğa, Beypazarı, Kızılcahamam, Keskin, and Polatlı. At those hypothetical sites, meteorological stations are available as well. In Figure 5.1 those sites are shown and in Table 5.1 their distance from the Ankara city center is presented. Digitized topography of the study area is given in Figure 5.2. For the pre-processing of meteorological data which is consequently used by the model algorithm itself, urban option has been used for Ankara (Keçiören) meteorological station and rural option has been used for the other alternatives. Each power plant is taken as located to be at the origin of a rectangular area having 40km x 40km dimensions. Emission characteristics of two different power plant alternatives are calculated by using the emission factors given in Table 5.2 following the amount of energy requirement and fossil fuel usage calculations in Chapter 4. The input parameters for the hypothetical power plants as stack characteristics and emissions of SO_2, NO_x and SPM are given in Table 5.3 which are conveniently adopted from in-use examples.

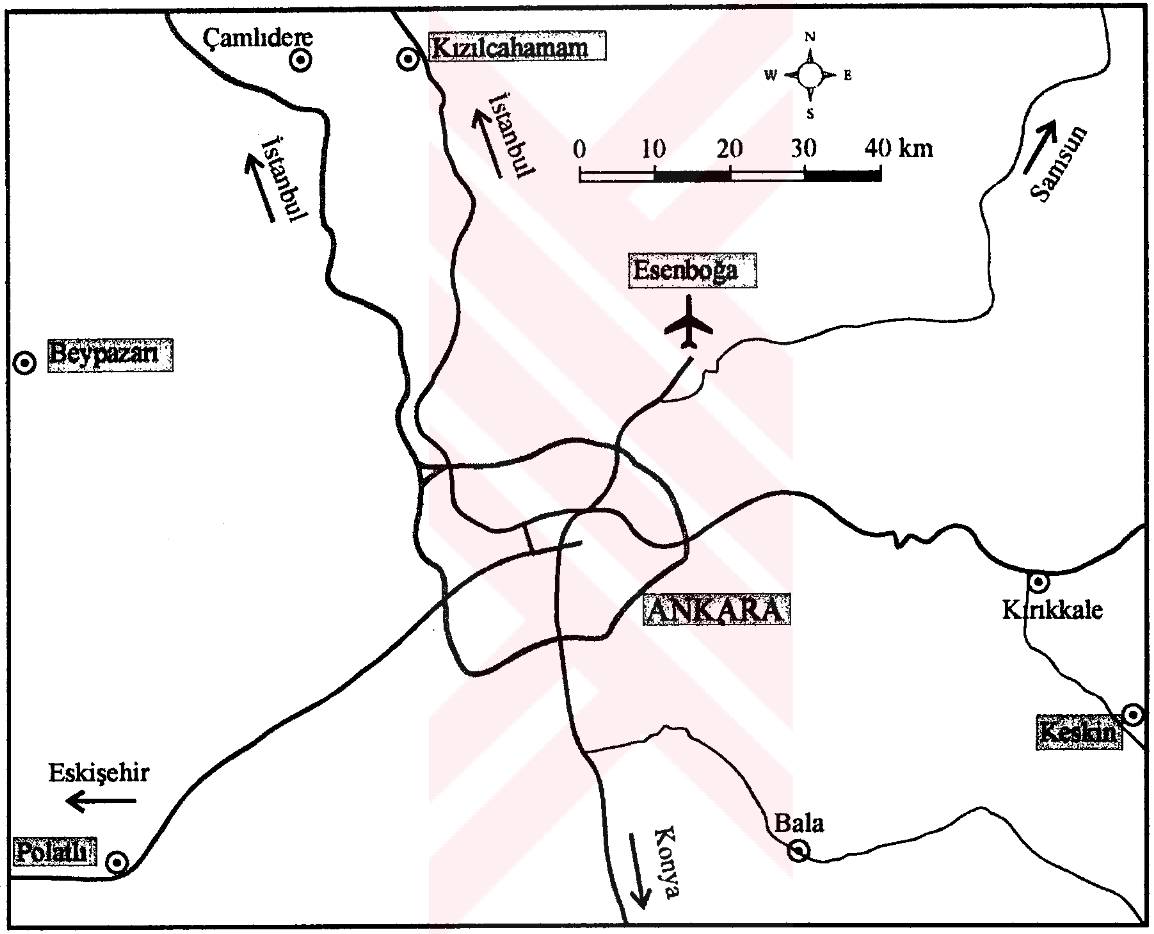

Figure 5.1. Locations of meteorological stations and hypothetical power plants

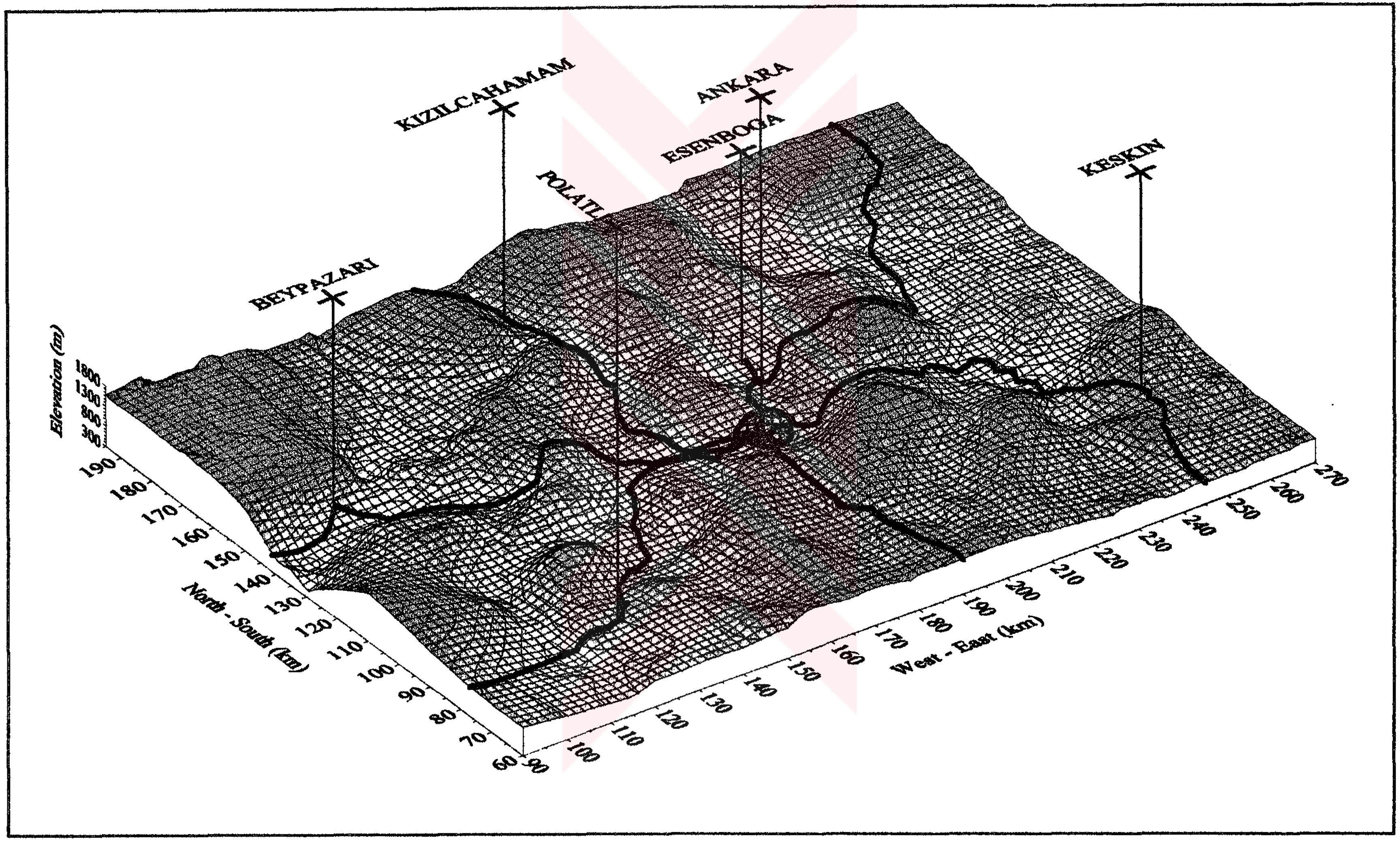

Figure 5.2 Digitized topography of the Ankara region

Table 5.1 Distance of the hypothetical thermal power plants from Ankara city center

Meteorological Stations	Distance (km)
Ankara (Keçiören)	6 NE
Esenboğa	24 NE
Beypazarı	83 NW
Keskin	72 SE
Kızılcahamam	61 NW
Polatlı	72 SW

Table 5.2 Emission factors for different thermal power plants

Parameters	CTPP[1]	NGCC[2]
Efficiency (%)	35	53
SO_2 (kg/GJ)	0.9838	0.005922
NO_2 (kg/GJ)	0.3341	0.255
PM (kg/GJ)	6.2787	0.001422

1 Conventional Coal Fired Thermal Power Plant
2 Natural Gas Combined Cycle Power Plant
Source: TEAŞ

Table 5.3 Input source parameters used for dispersion modeling

Sources	Emissions			Stack Parameters			
	SO_2 (g/s)	NO_x (g/s)	PM (g/s)	Exit Temperature (°K)	Exit Velocity (m/s)	Stack Diameter (m)	Stack Height (m)
CTPP	747.28	253.78	4769.17	373	15	10	100
NGCC	4.50	193.69	1.08	373	15	10	100

Table 5.4 Input parameters used for SPM dispersion modeling for CTPP

Particle Size Category	1	2	3	4
Diameter (μm)	0-1	1-2.5	2.5-10	10-50
Mass Fraction (ϕ_n)	0.06	0.04	0.25	0.65
Settling Velocity (cm/s)	0.0029	0.3645	0.4649	10.7100
Reflection Coefficient (γ_n)	0.95	0.85	0.83	0.50

Source: USEPA, 1992

For SPM dispersion modeling of the NGCC alternative, since all particles have a diameter between 0 and 1 μm, mass fraction is taken as 1.00 and settling velocity and reflection coefficient are calculated as 0.0119 cm/s and 0.92 respectively.

5.4 Simulation Results

A summary of the simulation results are given in Tables 5.5 and 5.6 for CTPP and NGCC correspondingly. Maximum hourly, maximum daily average and maximum yearly average Ground Level Concentrations (GLCs) of SO_2, NO_x and SPM and the distance of those maximum concentration points relative to the Ankara city center are summarized in those tables.

Figure 5.3 shows the estimated annual average SO_2 values for CTPP for all different sites of concern. As can be easily seen, for the sites of Beypazarı, Kızılcahamam, Polatlı and Keskin, the annual average GLCs are reduced to negligible amounts at distances far from the city center of Ankara (see also Figure 5.4.c, 5.4.d, 5.4.e, 5.4.f). Additionally, short term GLC values of maximum hourly and maximum daily average occur at least 65 km from the city center in all cases (see Table 5.5). For the other two sites, namely Ankara (Keçiören) and Esenboğa, as those sites are inside or just outside of the city center maximum hourly, daily and annual GLCs estimated are observed to be in and around the city center (see Table 5.5 and Figures 5.4.a and 5.4.b). However, for all of the sites investigated (including Keçiören) estimated maximum SO_2 GLC values are much smaller

Turkish Air Quality Regulations which are 150, 400 and 900 µg/m³ for maximum annual average, maximum daily average and maximum hourly respectively except for Ankara (Keçiören) for hourly maximum.

Table 5.5 Simulation results for CTPP

Meteorological Stations	Hourly Maximum		Daily Maximum		Yearly Maximum	
	GLC (µg/m³)	Distance [1] (km)	GLC (µg/m³)	Distance (km)	GLC (µg/m³)	Distance (km)
SO_2						
Ankara	1230.43	8.73 SE	255.84	11.88 SW	25.95	11.88 SW
Esenboğa	297.04	27.30 NE	118.30	20.62 NE	21.10	3.35 NE
Beypazarı	302.62	93.41 NW	72.06	92.05 NW	9.89	92.05 NW
Keskin	342.29	73.73 SE	60.24	64.83 SE	6.34	57.72 SE
Kızılcahamam	324.60	64.52 NW	98.77	64.52 NW	16.42	39.12 NW
Polatlı	428.52	74.33 SW	103.88	75.74 SW	11.71	87.32 SW
NO_x						
Ankara	417.86	8.73 SE	86.89	11.88 NE	8.81	11.88 SW
Esenboğa	100.87	27.30 NE	40.18	20.62 NE	7.17	3.35 NE
Beypazarı	102.77	93.41 NW	24.47	92.05 NW	3.36	92.05 NW
Keskin	116.24	73.73 SE	20.46	64.83 SE	2.25	57.72 SE
Kızılcahamam	110.23	64.52 NW	33.54	64.52 NW	5.58	39.12 NW
Polatlı	145.52	74.33 SW	35.28	75.74 SW	3.98	87.32 SW
SPM						
Ankara	32273.50	1.58 NE	2895.70	1.58 NE	147.23	3.35 NE
Esenboğa	76673.41	27.30 NE	6221.00	20.62 NE	361.87	20.62 NE
Beypazarı	37125.78	86.98 NW	3052.83	79.95 NW	246.24	79.95 NW
Keskin	41917.99	77.02 SE	4812.50	78.05 SE	120.52	78.05 SE
Kızılcahamam	93365.16	60.76 NW	27199.06	82.14 NW	1137.30	60.76 NW
Polatlı	21553.87	75.74 SW	2436.08	76.06 SW	248.33	70.47 SW

[1] Point occurrence as Distance from Ankara City Center

Similarly, estimated NO_x GLCs for all sites of investigation produced rather low values (see Table 5.5 and Figures 5.5, 5.6.a, 5.6.b, 5.6.c, 5.6.d, 5.6.e and 5.6.f) in comparison to the regulations which are 100 and 300 µg/m³ for maximum annual and maximum daily average respectively.

On the other hand, estimated SPM GLCs for the CTPP alternative (see Table 5.5 and Figures 5.7, 5.8.a, 5.8.b, 5.8.c, 5.8.d, 5.8.e and 5.8.f) show exceedence in annual average concentrations except two site alternatives (Ankara and Keskin), for which currently effective standard is 150 μg/m³ and severe exceedence for all site alternatives for daily averages for which the standard is stated as 300 μg/m³.

The simulation results for the case of NGCC alternative at six different sites for SO_2, NO_x and SPM are summarized in Table 5.6 and the annual average NO_x concentrations are shown in Figure 5.9 and Figure 5.10.a, 5.10.b, 5.10.c, 5.10.d, 5.10.e and 5.10.f. In this case, as expected, for all sites of choice and pollutants of concern there is no exceedence of standards of short or long term.

Further model simulations have been made in order to account for the possible treatment technology to be installed in the CTPP alternative. This, in turn appears to be a must to be in compliance with the currently effective stack gas effluent standards for new facilities. Results of model simulations, assuming a CTPP equipped with an FGD system of 95% SO_2 removal efficiency and Electrostatic Precipitator (ESP) system of 99% efficiency are summarized in Table 5.6 for all site alternatives. As expected, such a measure will ensure reducing potential GLCs of SO_2 and SPM dramatically.

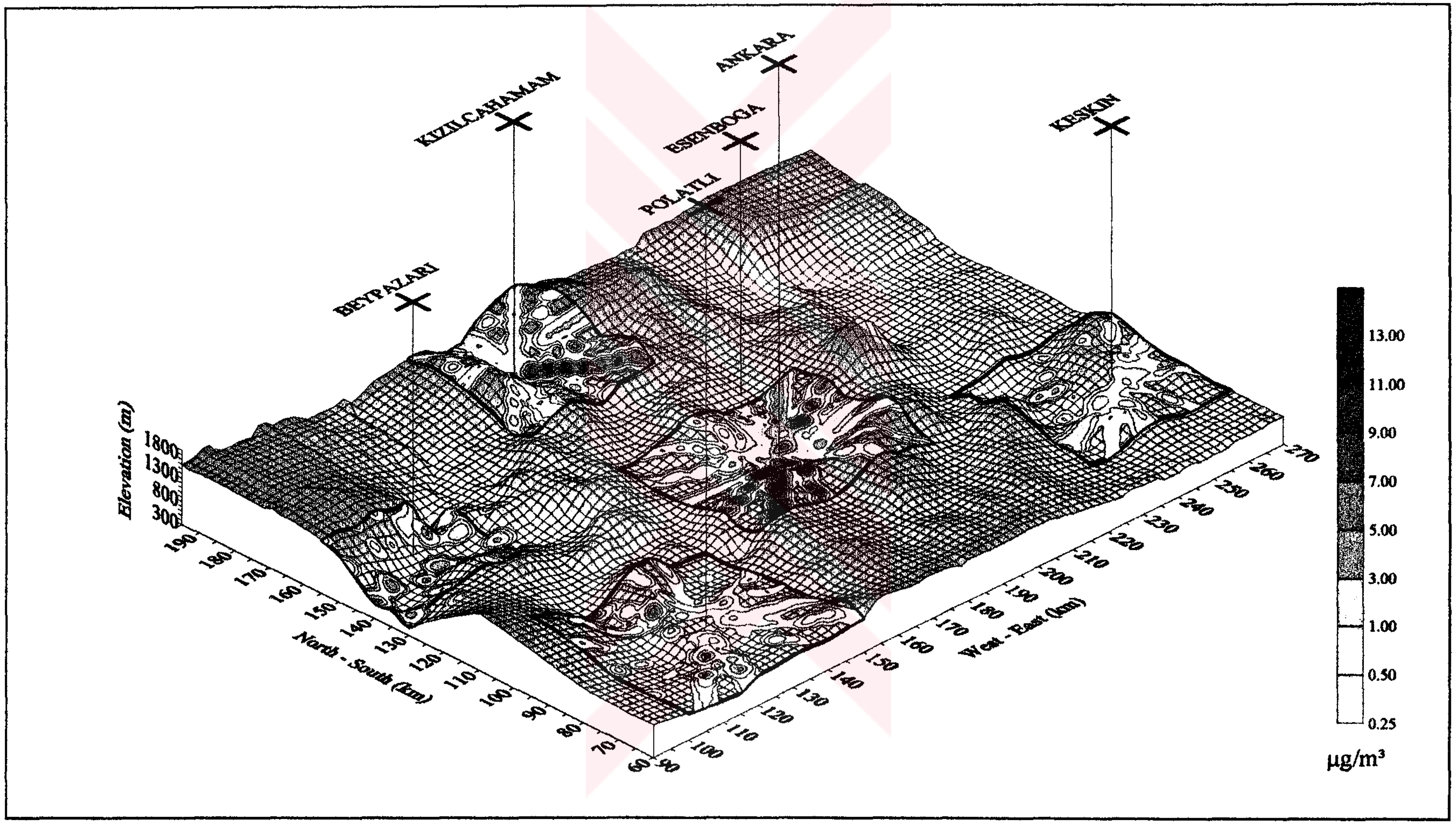

Figure 5.3 Estimated annual average SOx GLCs for CTPP alternative at different sites

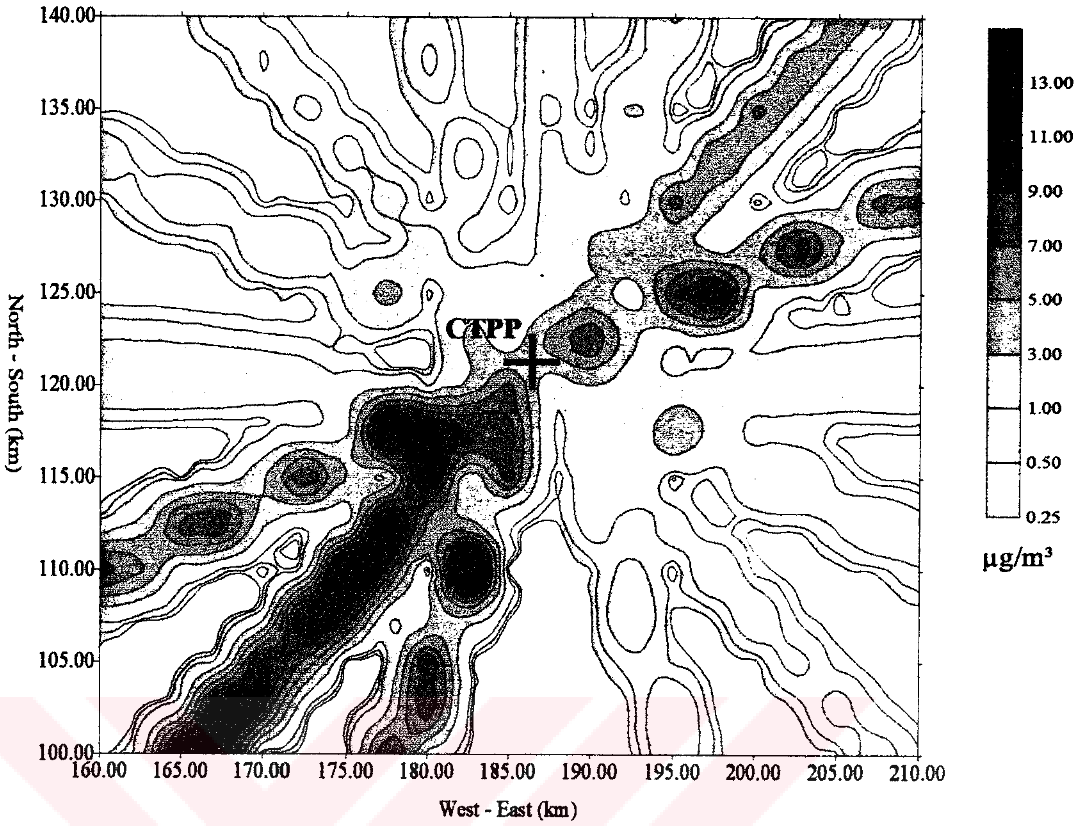

Figure 5.4.a Estimated annual average SOx GLCs for CTPP at Ankara

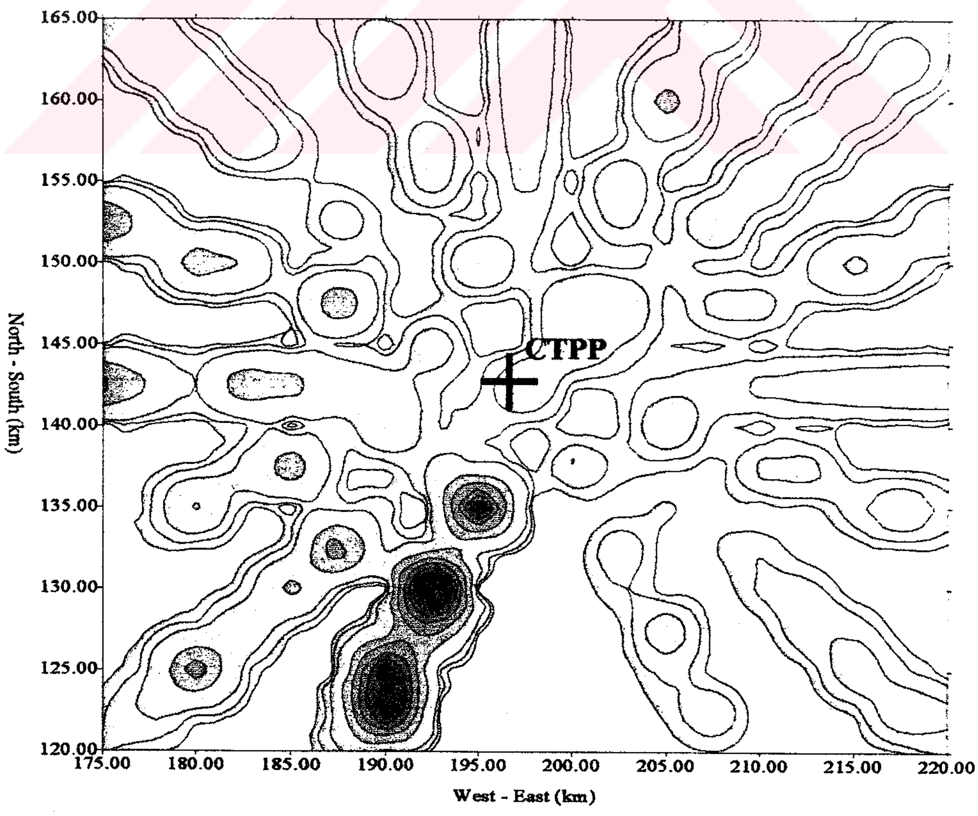

Figure 5.4.b Estimated annual average SOx GLCs for CTPP at Esenboga

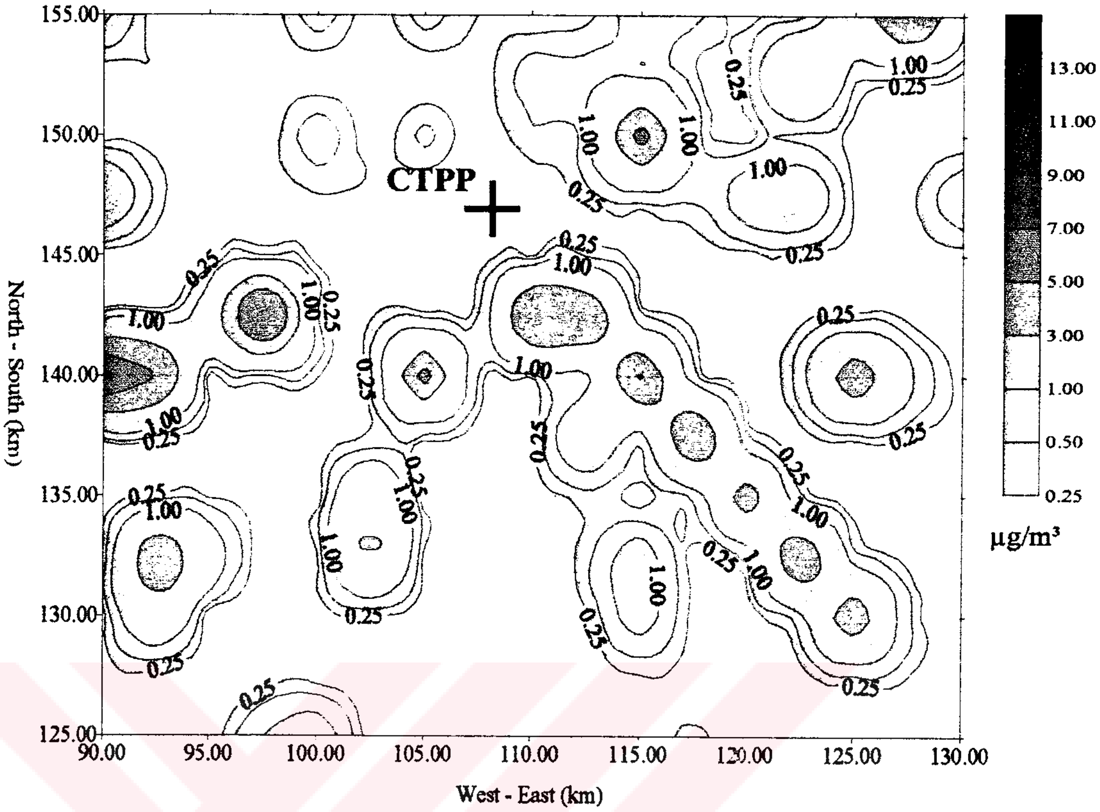

Figure 5.4.c Estimated annual average SOx GLCs for CTPP at Beypazari

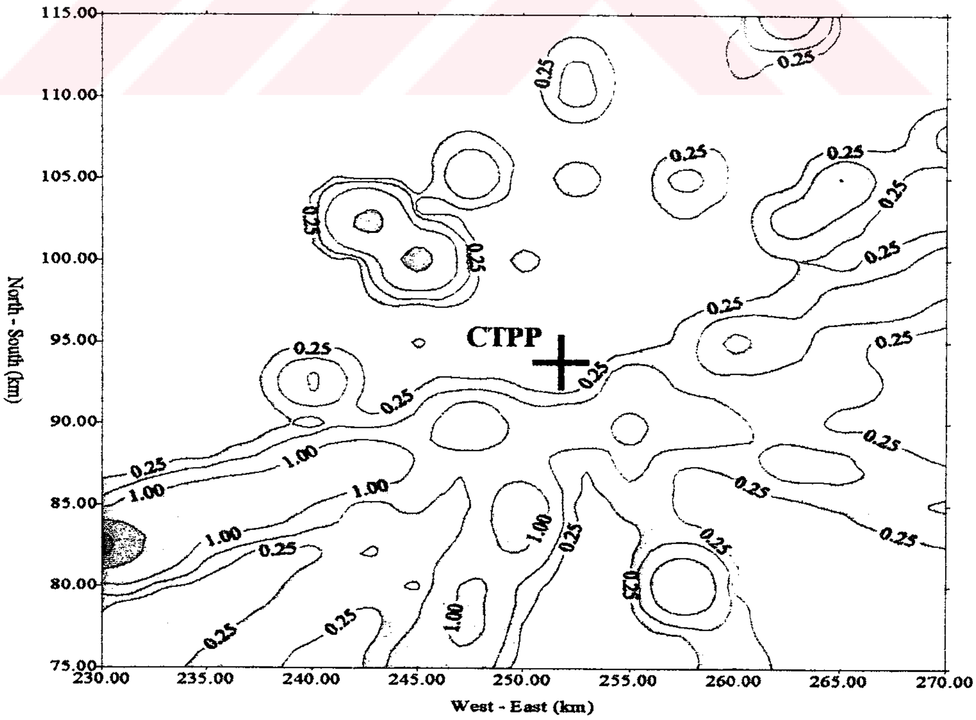

Figure 5.4.d Estimated annual average SOx GLCs for CTPP at Keskin

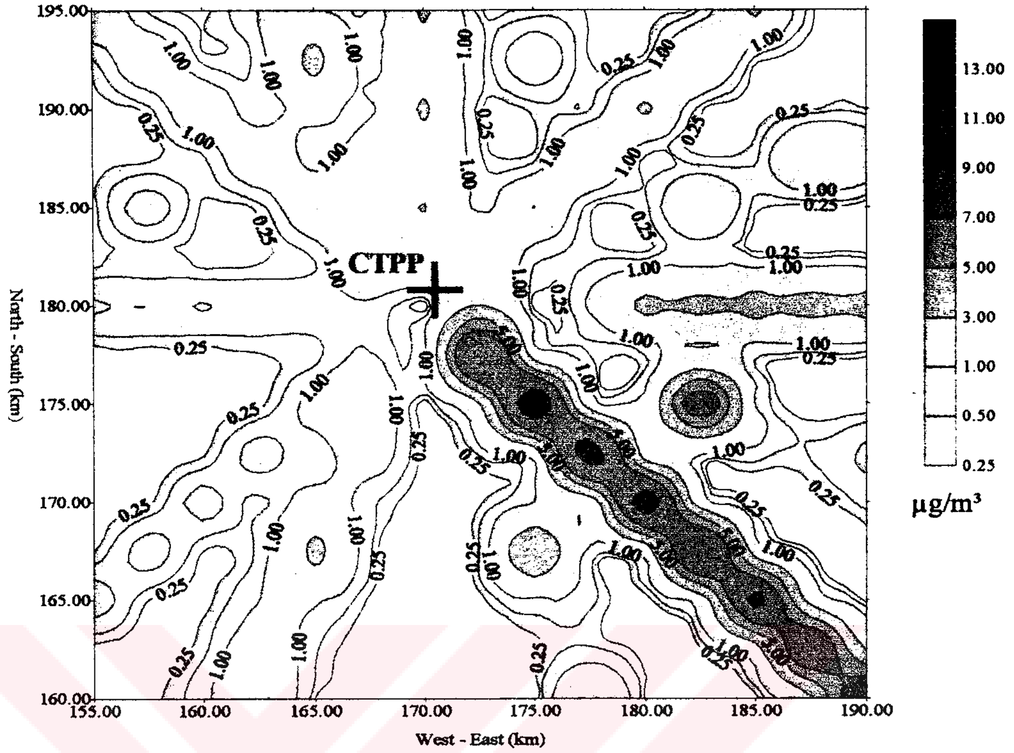

Figure 5.4.e Estimated annual average SOx GLCs for CTPP at Kizilcahamam

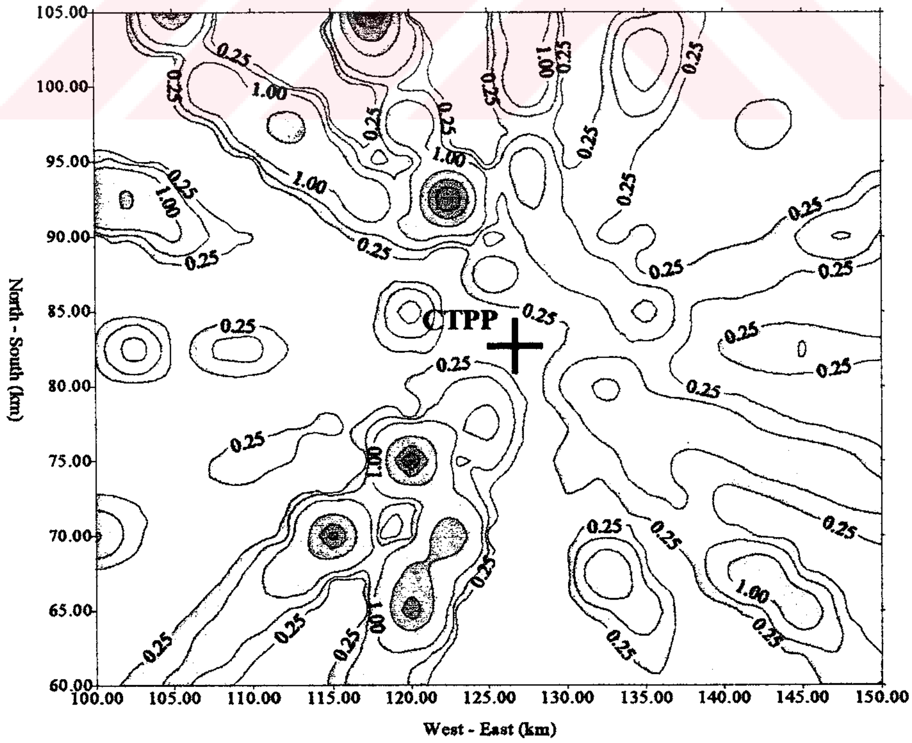

Figure 5.4.f Estimated annual average SOx GLCs for CTPP at Polatli

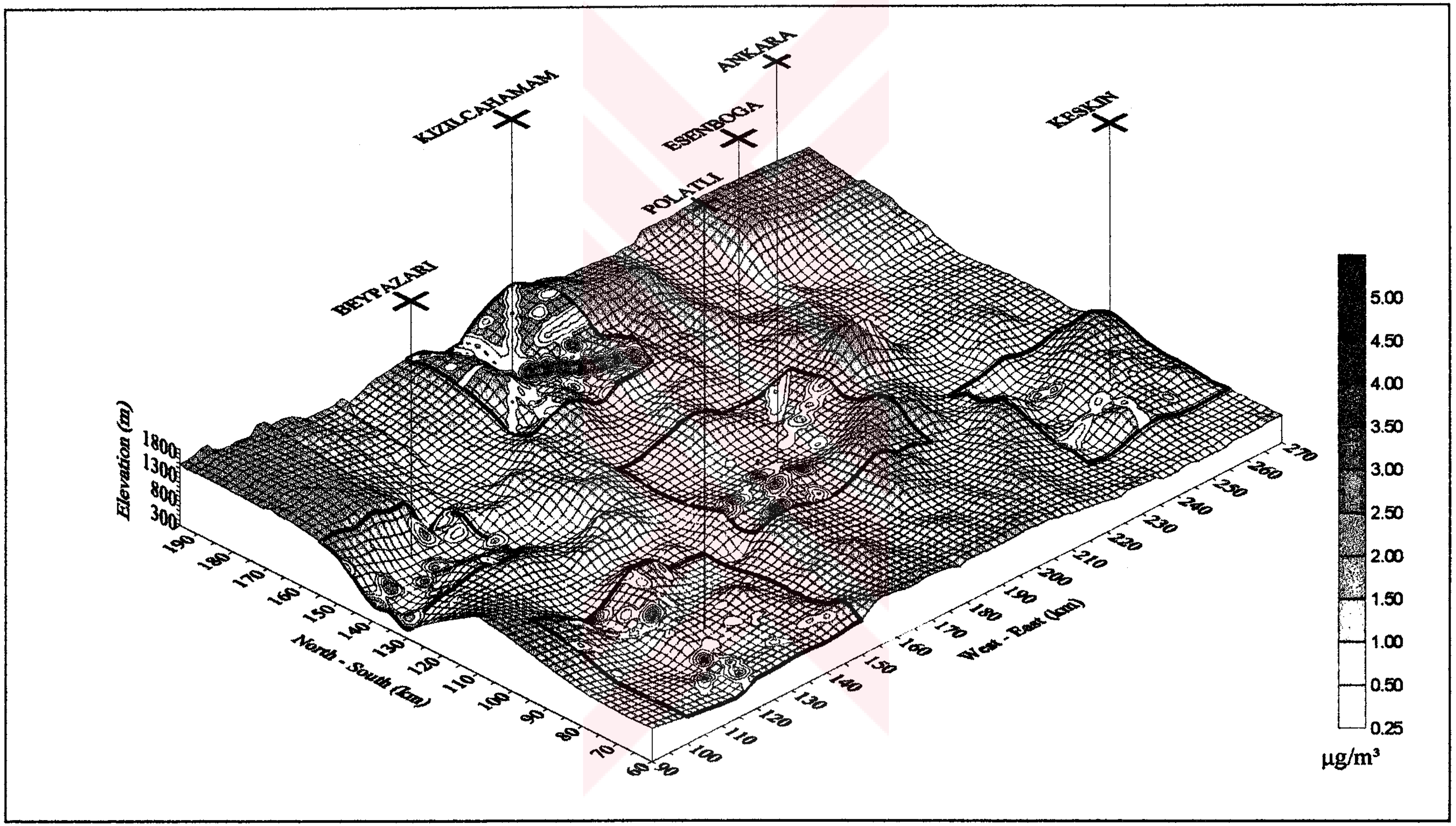

Figure 5.5 Estimated annual average NOx GLCs for CTPP alternative at different sites

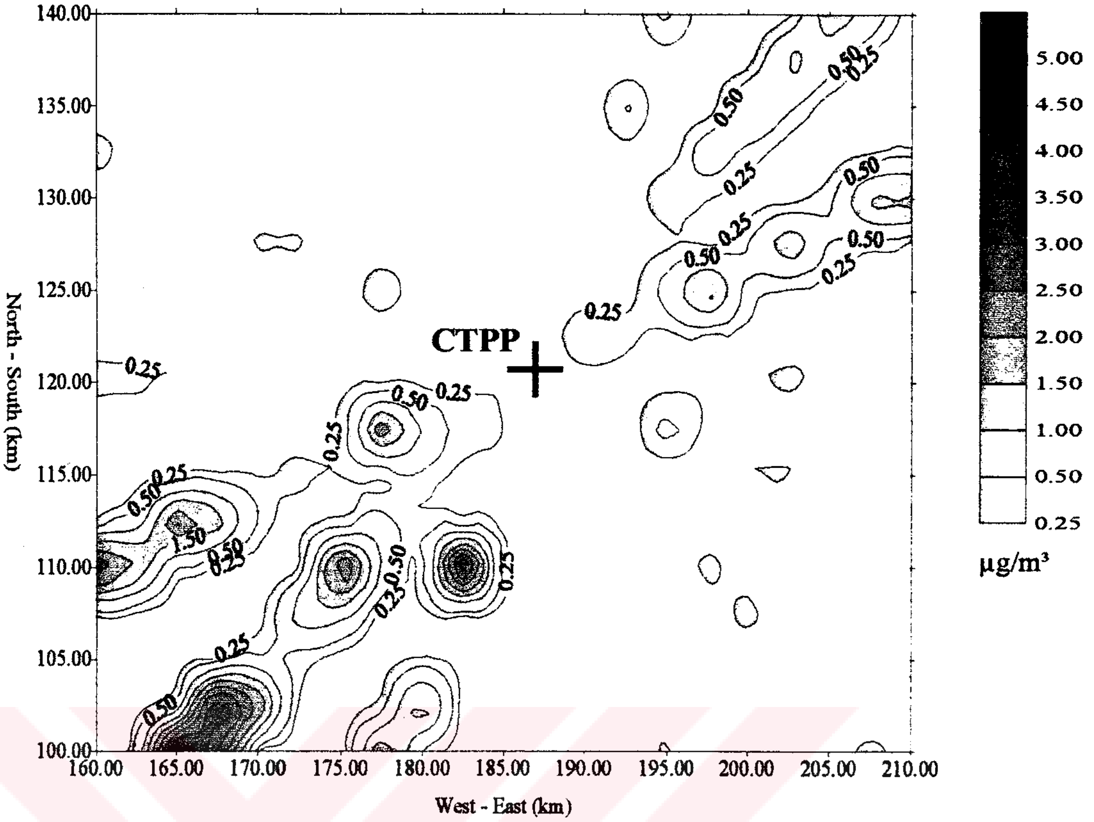

Figure 5.6.a Estimated annual average NOx GLCs for CTPP at Ankara

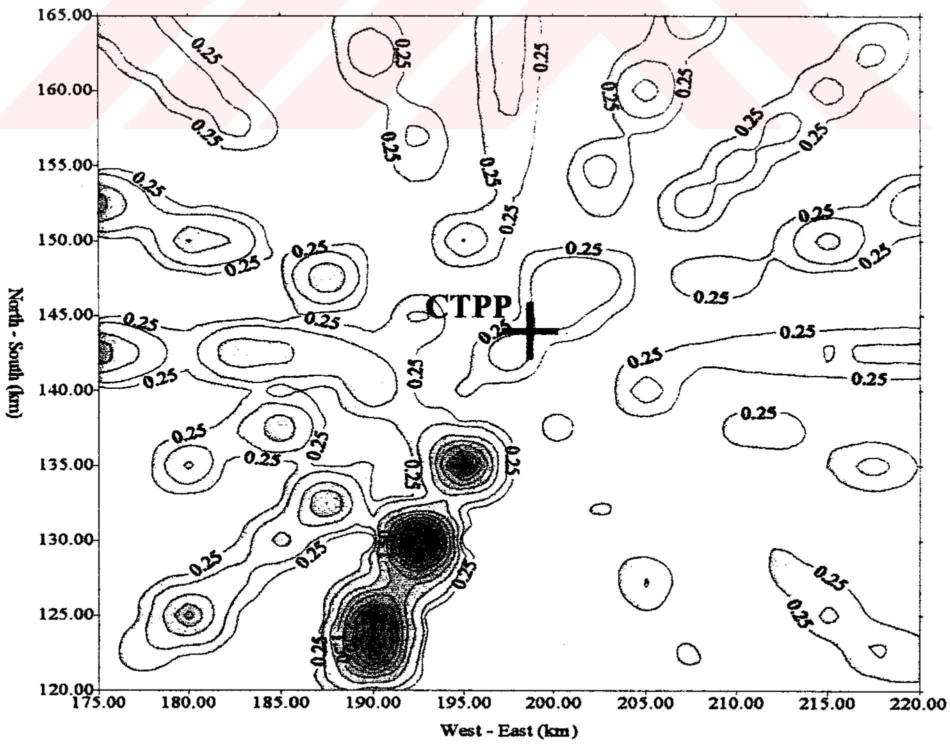

Figure 5.6.b Estimated annual average NOx GLCs for CTPP at Esenboga

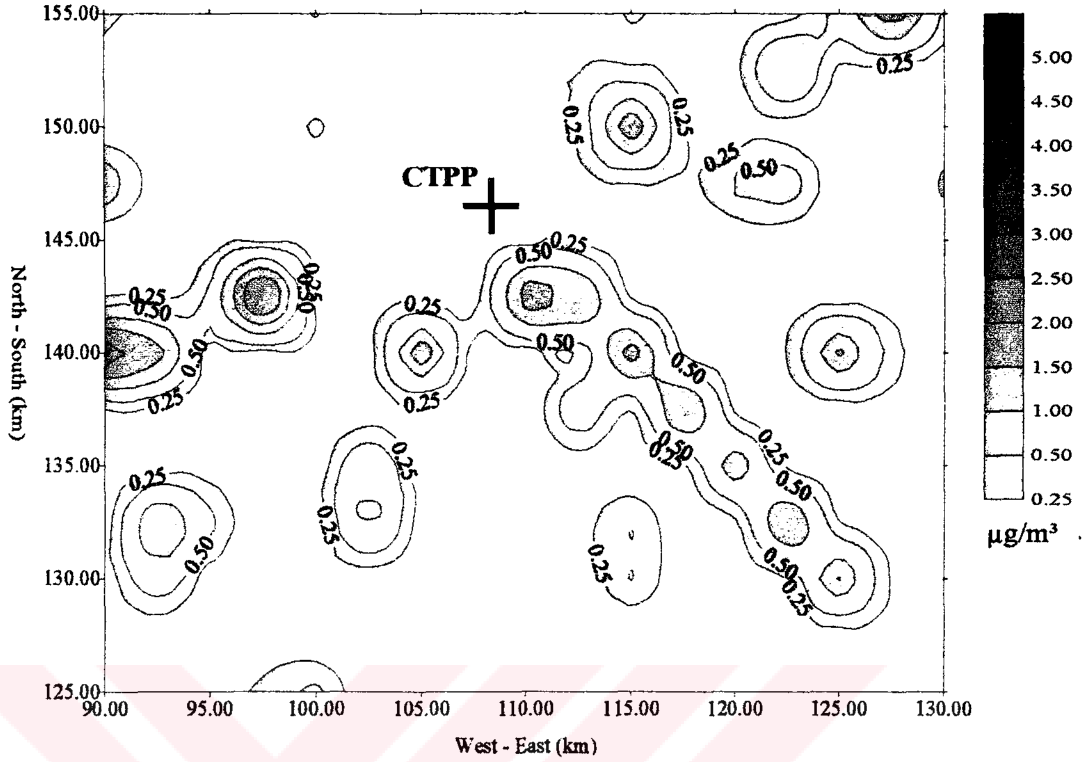

Figure 5.6.c Estimated annual average NOx GLCs for CTPP at Beypazari

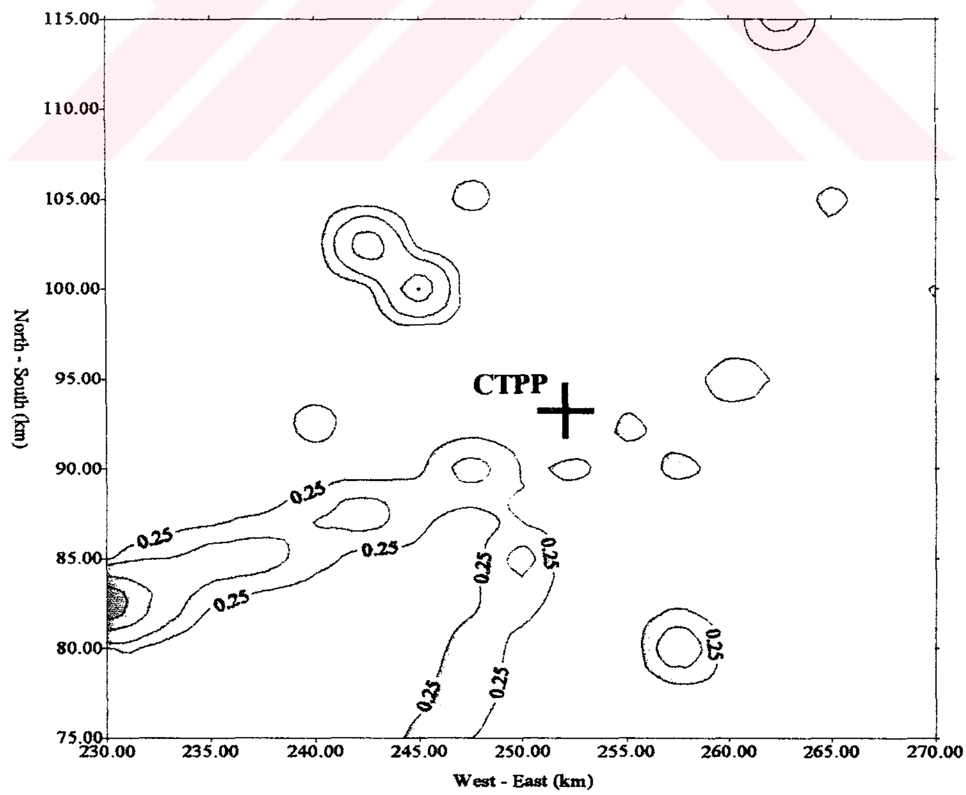

Figure 5.6.d Estimated annual average NOx GLCs for CTPP at Keskin

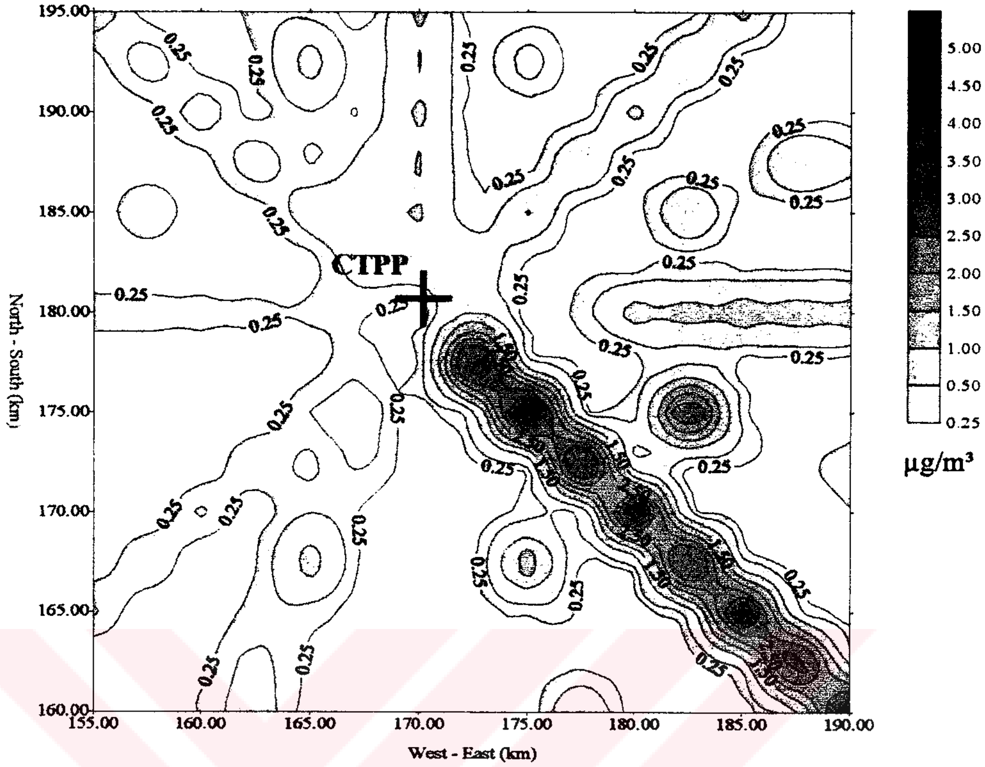

Figure 5.6.e Estimated annual average NOx GLCs for CTPP at Kizilcahamam

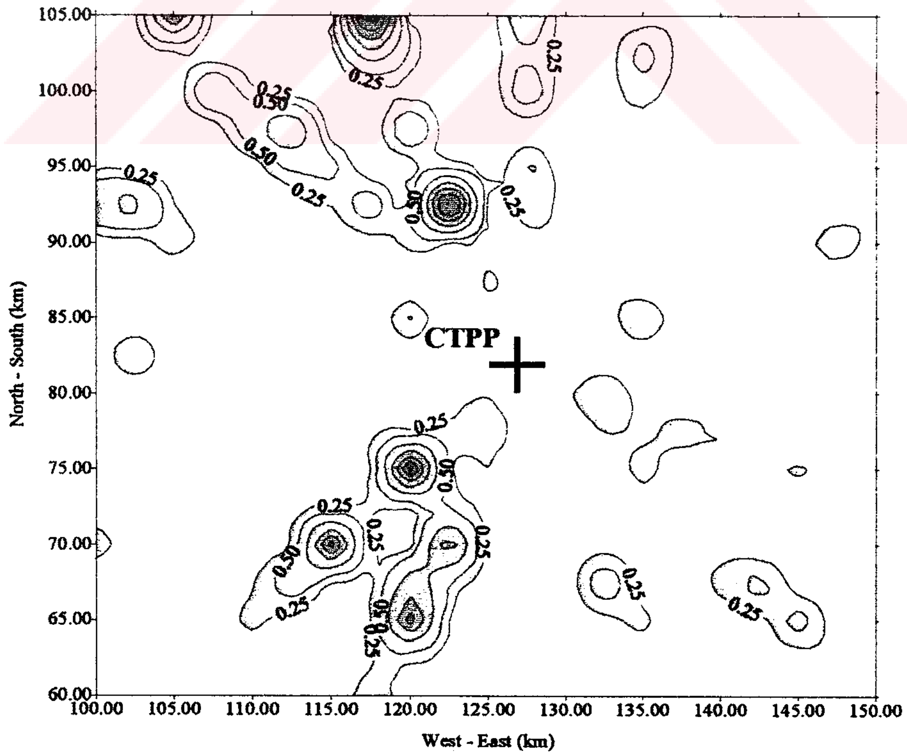

Figure 5.6.f Estimated annual average NOx GLCs for CTPP at Polatli

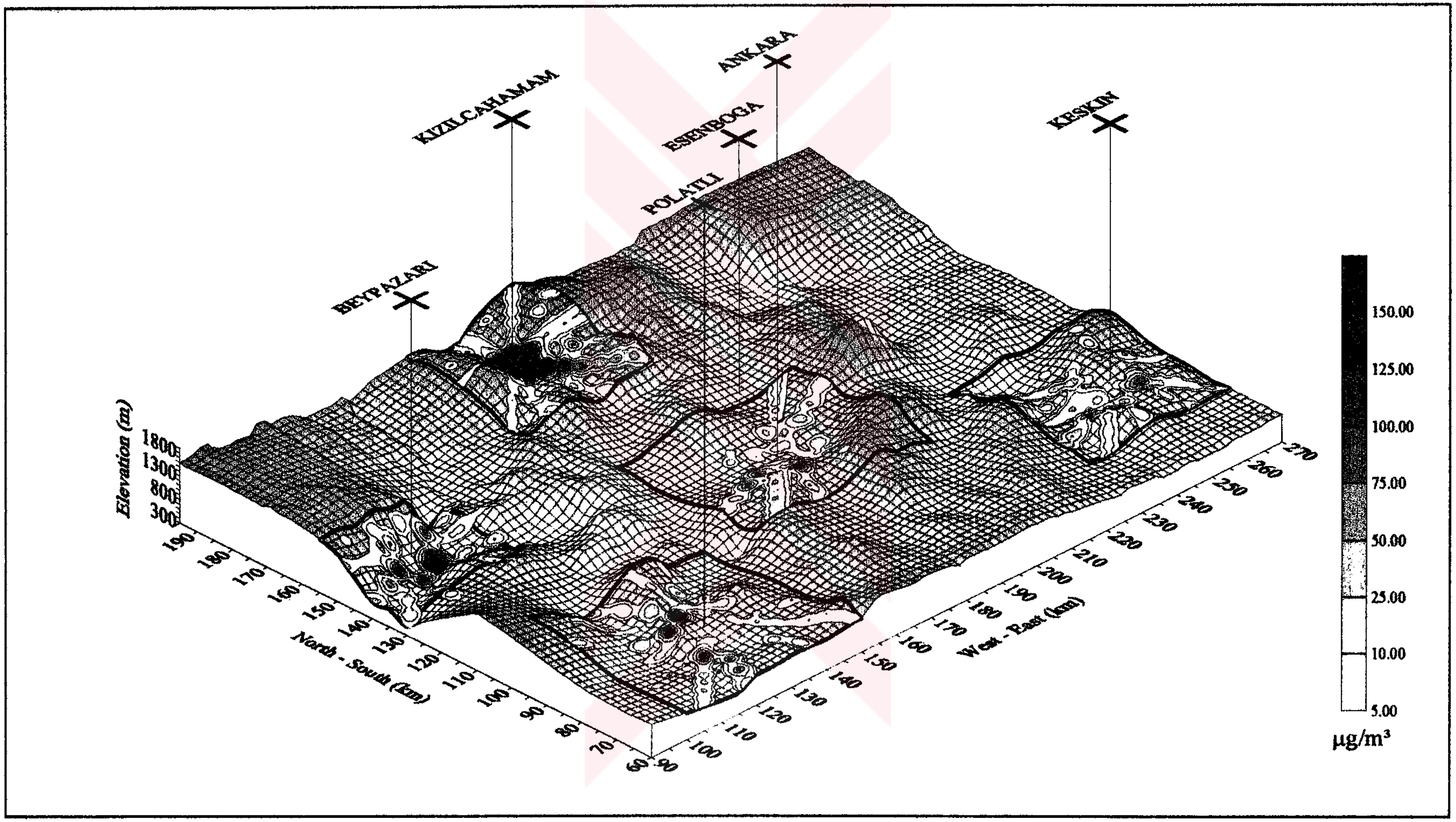

Figure 5.7 Estimated annual SPM GLCs for CTPP alternative at different sites

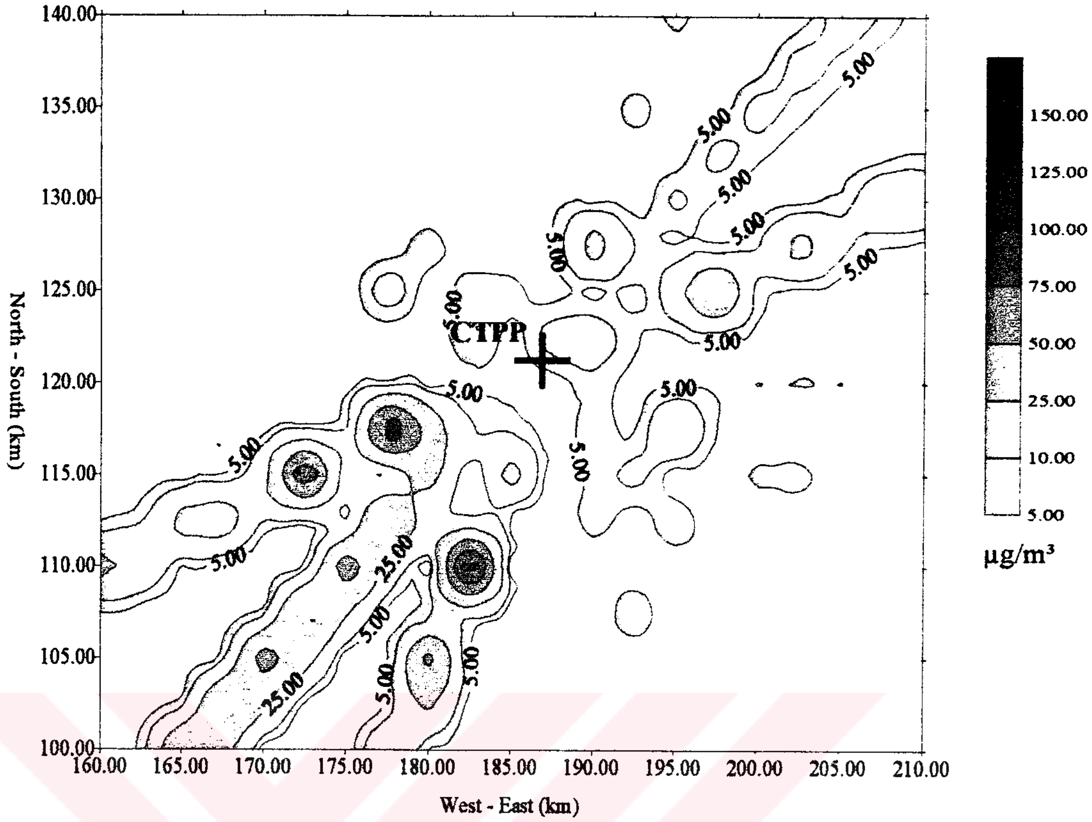

Figure 5.8.a Estimated annual average SPM GLCs for CTPP at Ankara

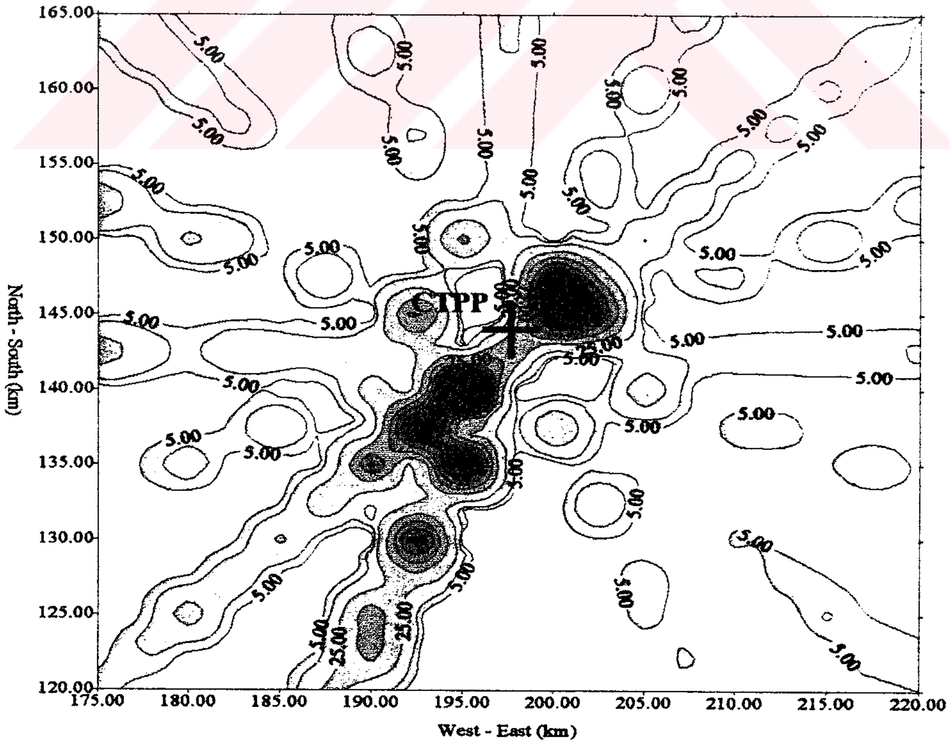

Figure 5.8.b Estimated annual average SPM GLCs for CTPP at Esenboga

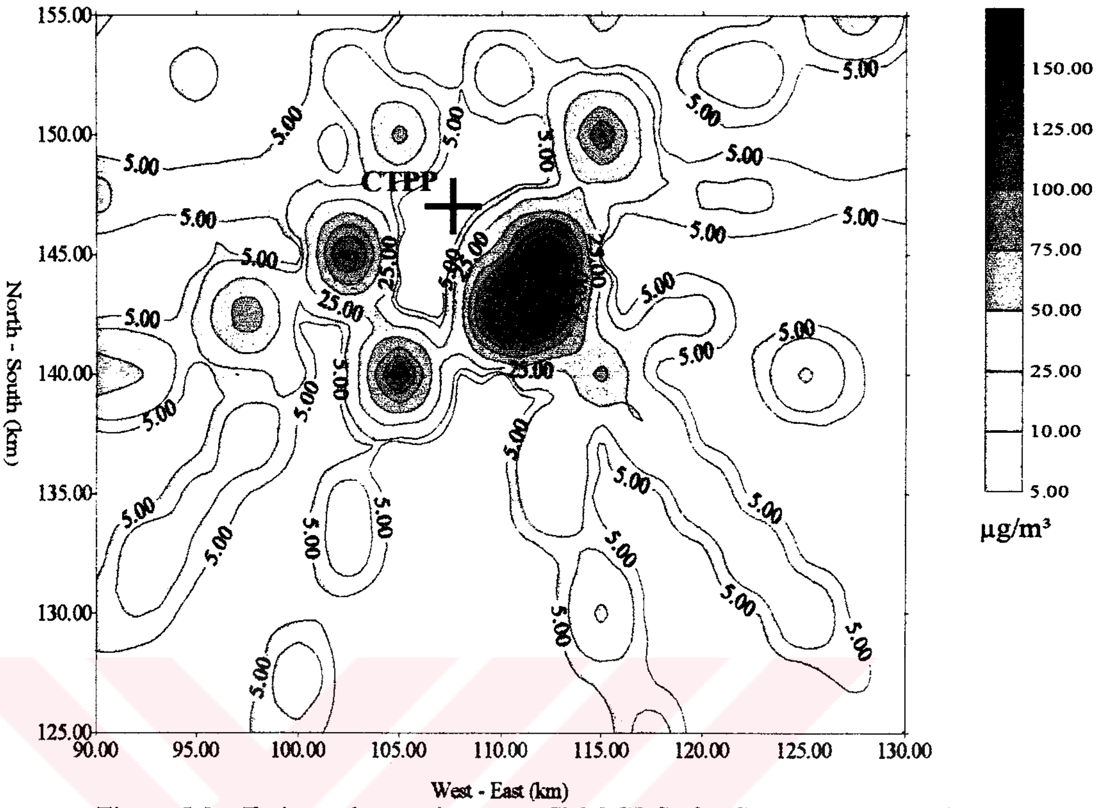

Figure 5.8.c Estimated annual average SPM GLCs for CTPP at Beypazari

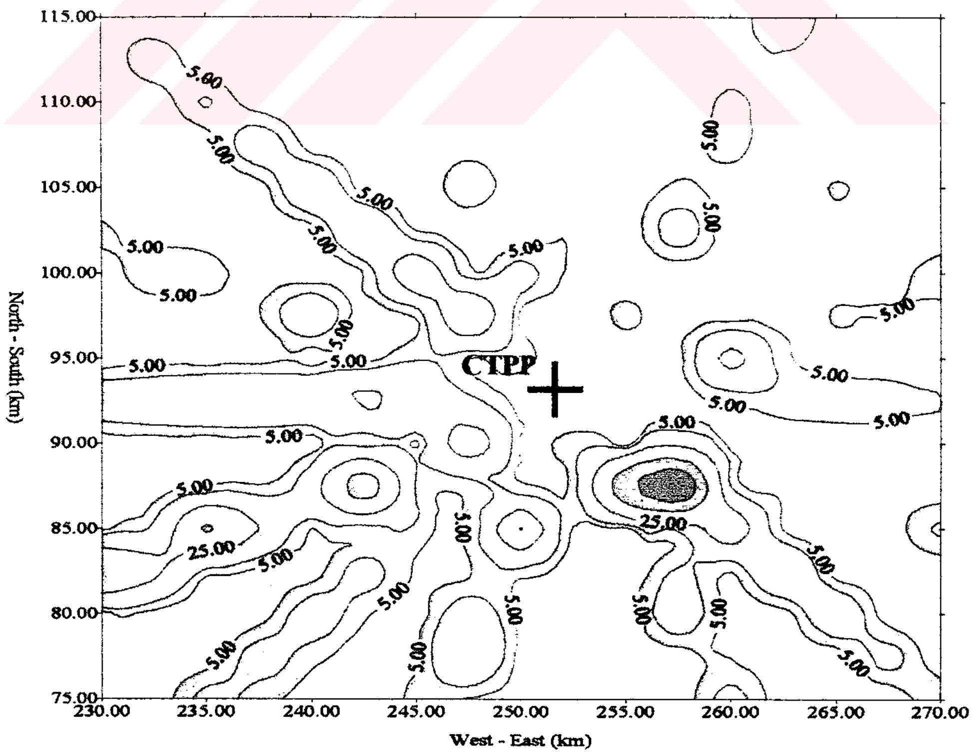

Figure 5.8.d Estimated annual average SPM GLCs for CTPP at Keskin

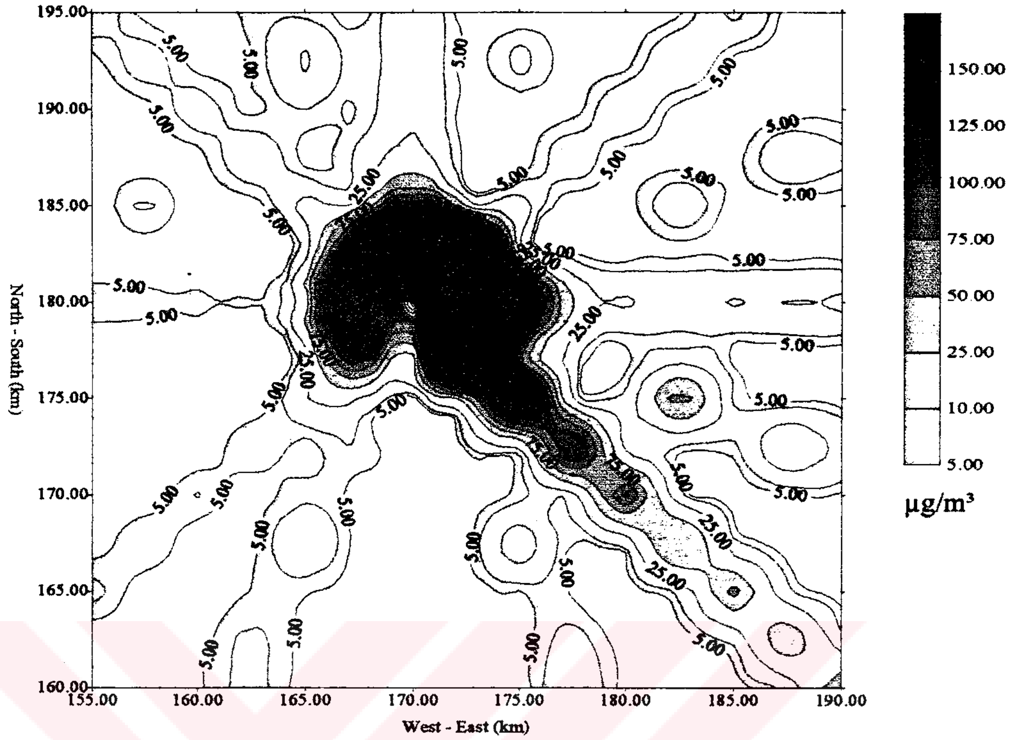

Figure 5.8.e Estimated annual average SPM GLCs for CTPP at Kizilcahamam

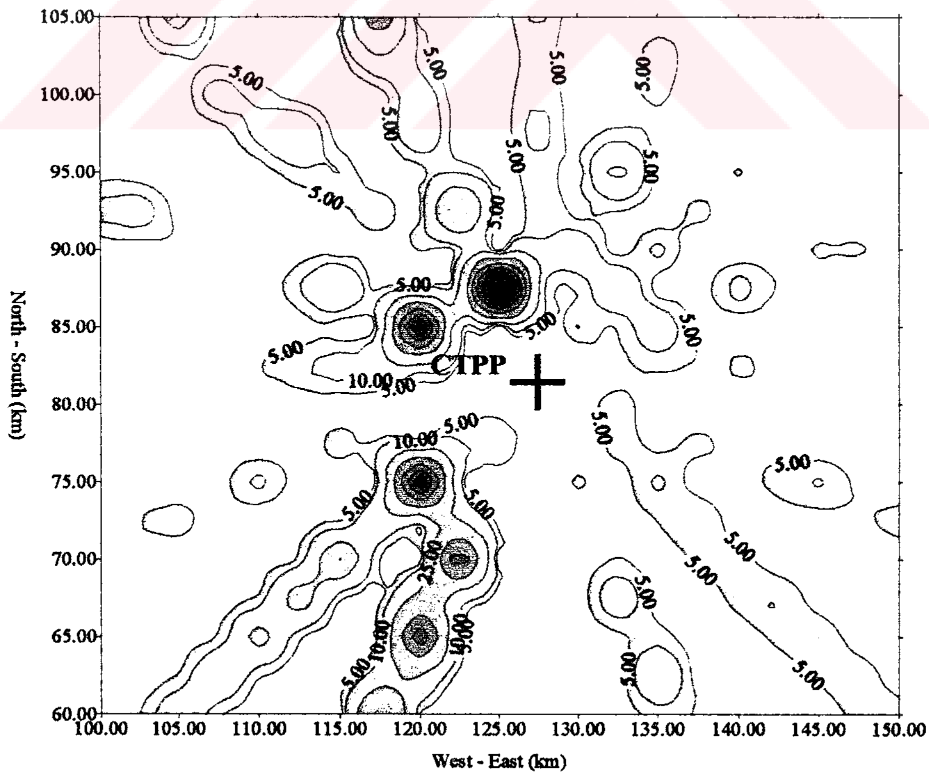

Figure 5.8.f Estimated annual average SPM GLCs for CTPP at Polatli

Table 5.6 Simulation results for NGCC

Meteorological Stations	Hourly Maximum		Daily Maximum		Yearly Maximum	
	GLC ($\mu g/m^3$)	Distance [1] (km)	GLC ($\mu g/m^3$)	Distance (km)	GLC ($\mu g/m^3$)	Distance (km)
SO_2						
Ankara	7.41	8.73 SE	1.54	11.88 SW	0.16	11.88 SW
Esenboğa	1.79	33.56 NE	0.71	10.55 NE	0.13	10.55 NE
Beypazarı	1.82	93.41 NW	0.43	92.05 NW	0.06	92.05 NW
Keskin	2.06	63.56 SE	0.36	58.50 SE	0.04	57.72 SE
Kızılcahamam	1.95	55.32 NW	0.59	55.32 NW	0.01	55.32 NW
Polatlı	2.58	75.74 SW	0.63	81.27 SW	0.07	71.32 SW
NO_x						
Ankara	318.93	8.73 SE	66.31	11.88 SW	6.73	11.88 SW
Esenboğa	76.99	33.56 NE	30.66	10.55 NE	5.47	10.55 NE
Beypazarı	78.44	93.41 NW	18.68	92.05 NW	2.57	92.05 NW
Keskin	88.72	63.56 SE	15.61	58.50 SE	1.72	57.72 SE
Kızılcahamam	84.13	55.32 NW	25.60	55.32 NW	4.26	55.32 NW
Polatlı	111.07	75.74 SW	26.93	81.27 SW	3.03	71.32 SW
SPM						
Ankara	1.72	8.73 SE	0.36	11.88 SW	0.04	11.88 SW
Esenboğa	0.42	33.56 NE	0.17	10.55 NE	0.03	10.55 NE
Beypazarı	0.42	93.41 NW	0.10	92.05 NW	0.01	92.05 NW
Keskin	0.48	63.56 SE	0.09	58.50 SE	0.01	57.72 SE
Kızılcahamam	0.45	55.32 NW	0.14	55.32 NW	0.02	55.32 NW
Polatlı	0.59	75.74 SW	0.14	81.27 SW	0.02	71.32 SW

[1] Point occurrence as Distance from Ankara City Center

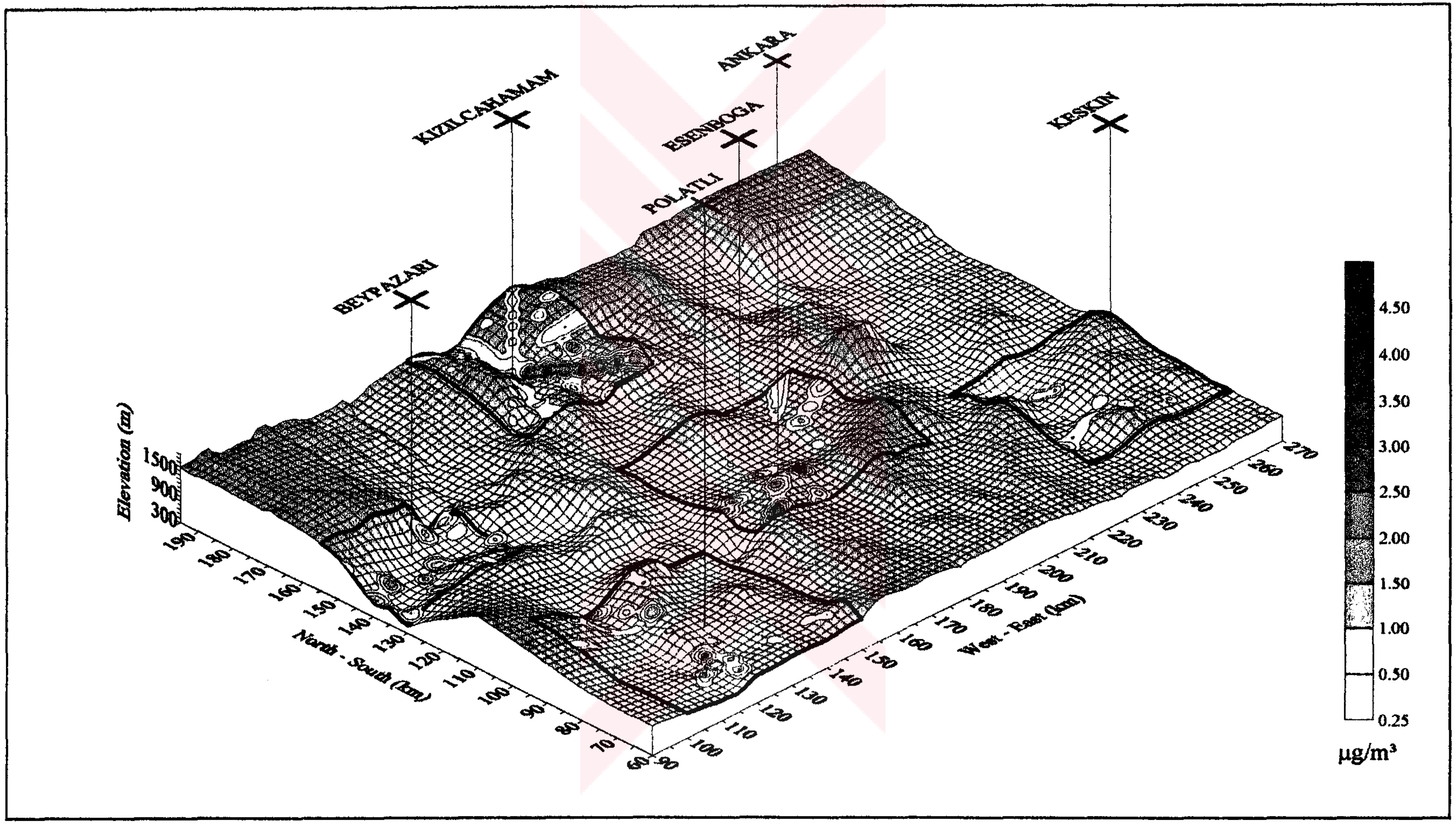

Figure 5.9 Estimated annual average NOx GLCs for NGCC alternative at different sites

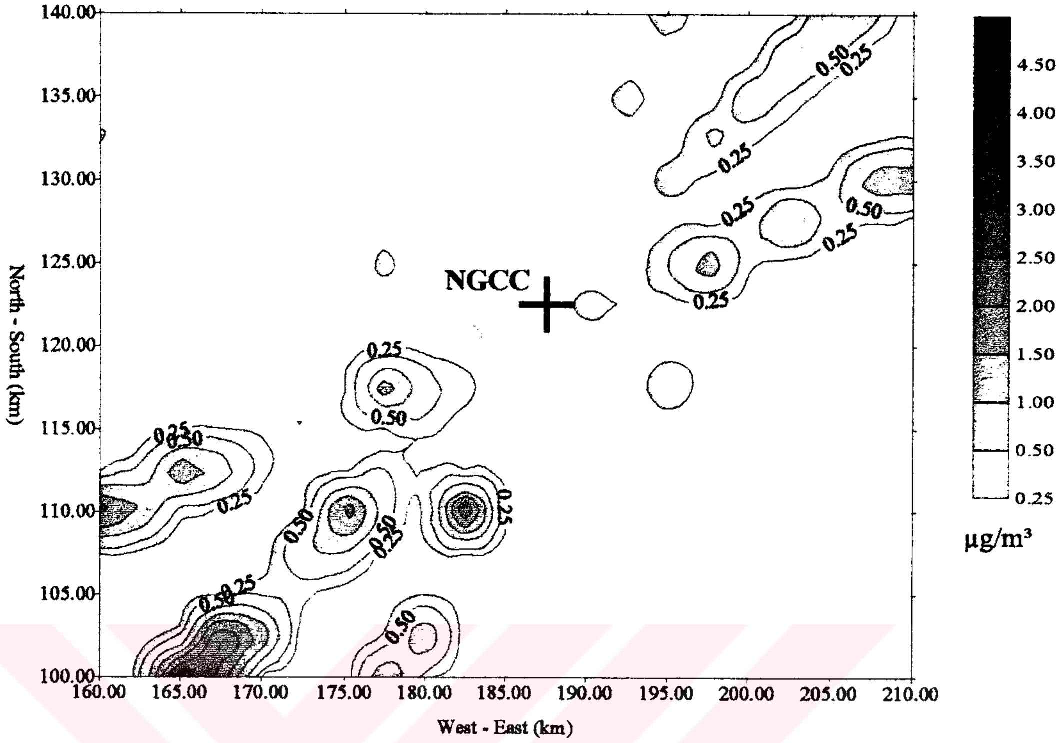

Figure 5.10.a Estimated annual average NOx GLCs for NGCC at Ankara

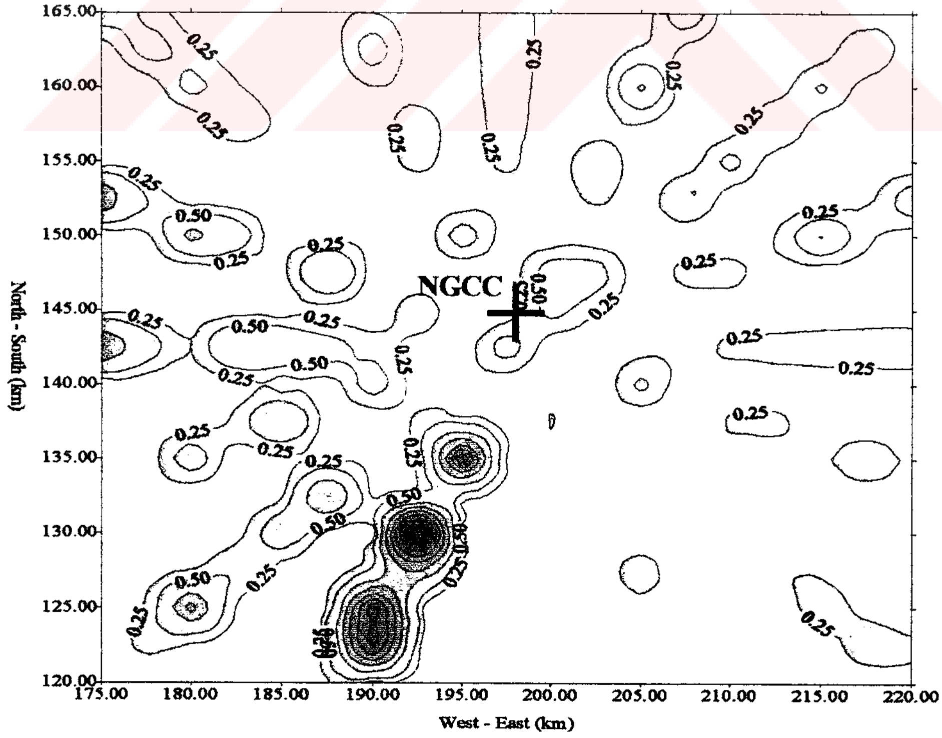

Figure 5.10.b Estimated annual average NOx GLCs for NGCC at Esenboga

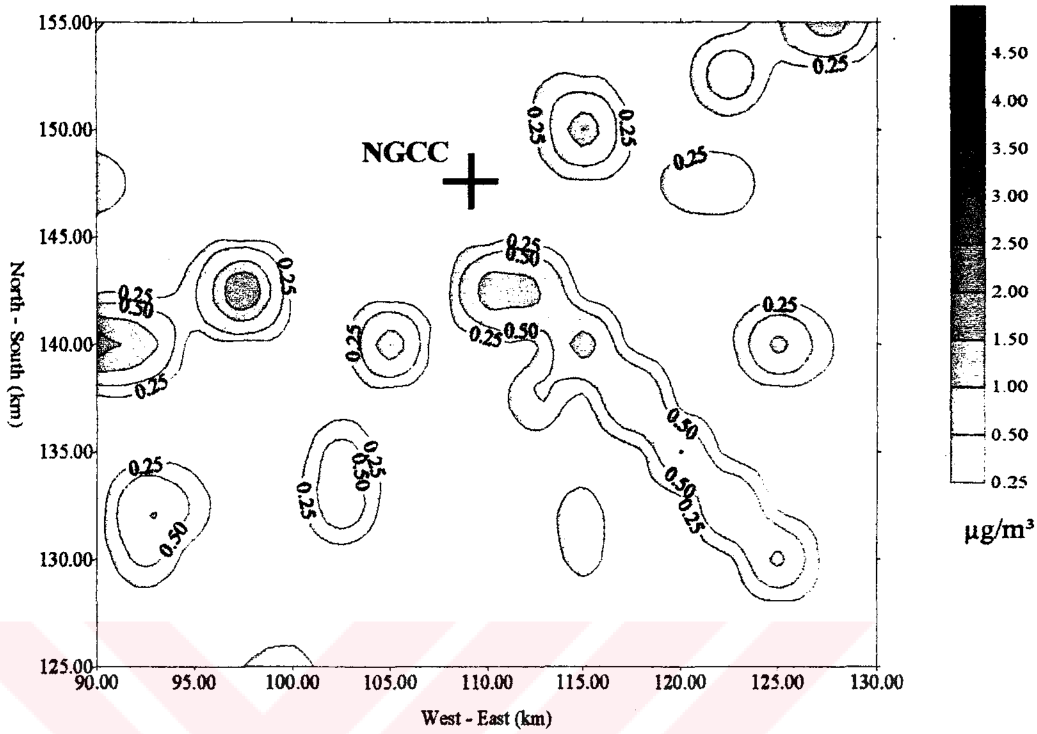

Figure 5.10.c Estimated annual average NOx GLCs for NGCC at Beypazari

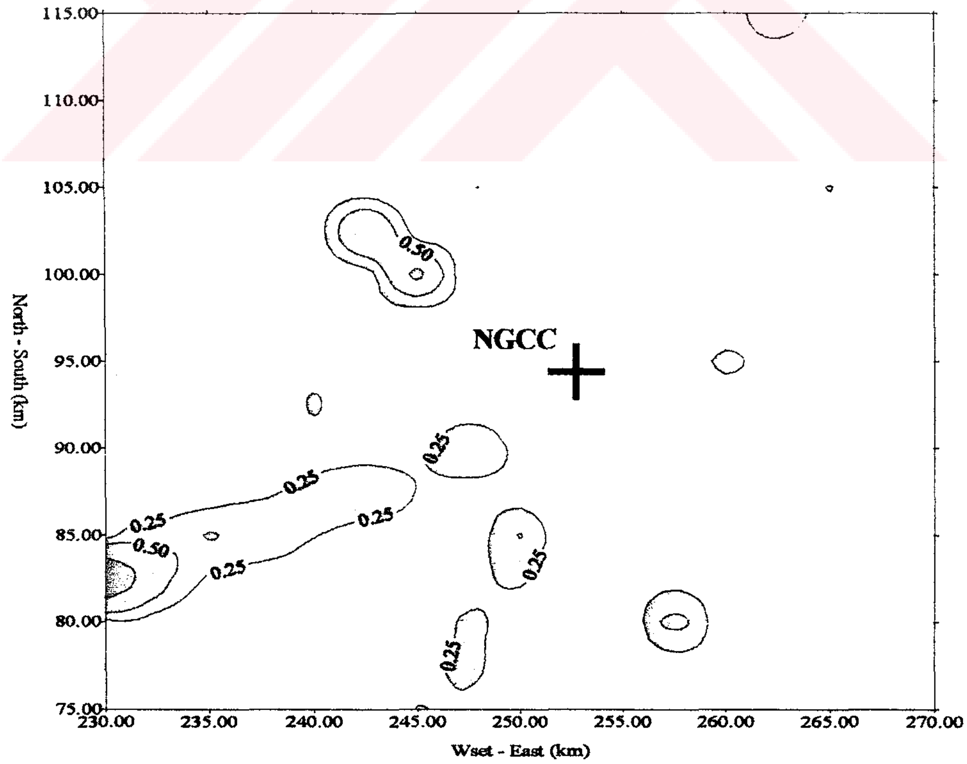

Figure 5.10.d Estimated annual average NOx GLCs for NGCC at Keskin

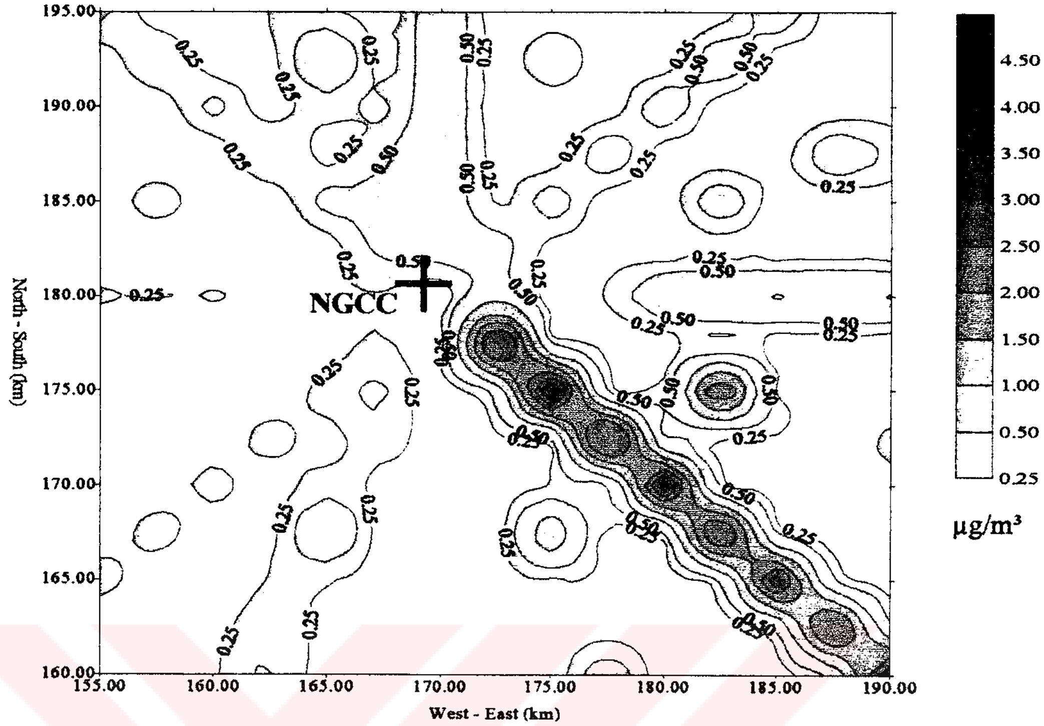

Figure 5.10.e Estimated annual average NOx GLCs for NGCC at Kizilcahamam

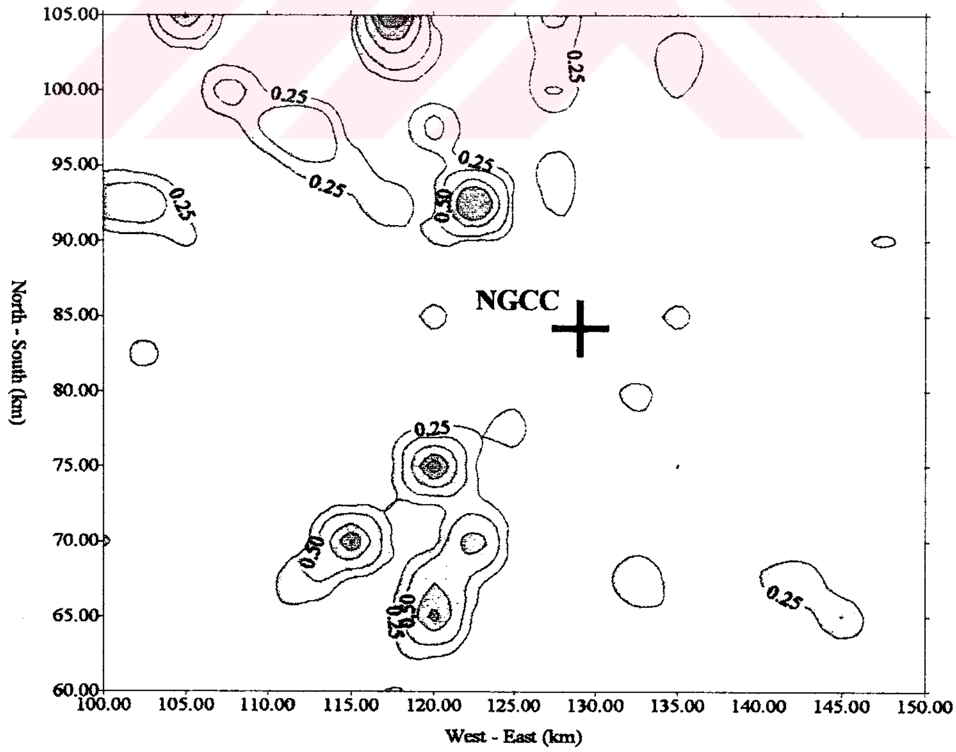

Figure 5.10.f Estimated annual average NOx GLCs for NGCC at Polatli

Table 5.7 Simulation results for CTPP equipped with treatment technology

Meteorological Stations	Hourly Maximum		Daily Maximum		Yearly Maximum	
	GLC ($\mu g/m^3$)	Distance [1] (km)	GLC ($\mu g/m^3$)	Distance (km)	GLC ($\mu g/m^3$)	Distance (km)
SO_2 (FGD with 95% efficiency)						
Ankara	61.52	8.73 SE	12.79	11.88 SW	1.30	11.88 SW
Esenboğa	14.85	27.30 NE	5.90	20.62 NE	1.06	3.35 NE
Beypazarı	15.10	93.41 NW	3.60	92.05 NW	0.49	92.05 NW
Keskin	17.10	73.73 SE	3.00	64.83 SE	0.32	57.72 SE
Kızılcahamam	16.25	64.52 NW	4.95	64.52 NW	0.82	39.12 NW
Polatlı	21.45	74.33 SW	5.20	75.74 SW	0.59	87.32 SW
SPM (ESP with 99% efficiency)						
Ankara	75.85	8.73 SE	15.73	11.88 SW	1.59	11.88 SW
Esenboğa	18.68	27.30 NE	7.32	20.62 NE	1.31	3.35 NE
Beypazarı	18.72	93.41 NW	4.46	92.05 NW	0.62	92.05 NW
Keskin	20.96	73.73 SE	3.77	64.83 SE	0.41	57.72 SE
Kızılcahamam	19.94	64.52 NW	6.07	64.52 NW	1.01	39.12 NW
Polatlı	26.24	74.33 SW	6.37	75.74 SW	0.74	87.32 SW

[1] Point occurrence as Distance from Ankara City Center

5.5 Discussion on the Simulation Results

By the use of ISCST simulation model, GLCs of SO_2, NO_x and SPM originating from power plant generating electricity for domestic heating for city of Ankara have been estimated. According to the simulation results for four site alternatives excluding Ankara (Keçiören) and Esenboğa, there would be no contribution to the air pollution levels in Ankara city for the period of 1991-1992 winter season.

As expected, the maximum contribution to the air pollution levels in Ankara would occur for the hypothetical alternative of CTPP located in the city center of Ankara (Keçiören). However, even with this extremely unreasonable site selection choice (which implies a single tall stack in the middle of the city as opposed to thousands of discrete sources distributed over the city area) the potential air pollution levels in the city would be much lower than what was measured in Ankara during the period of concern.

According to an emission inventory conducted by Atımtay (see Appendix F) domestic heating in the city contributes to 59% of SO_2, 29% of NO_x and 63% of SPM concentrations annually. Since the winter season in Ankara is about six months, residential and commercial heating activities contributes only to the winter season pollution levels. In order to calculate the contribution of domestic heating on the GLCs during winter season, amount of emissions from industrial sources and traffic is taken as half of the annual total whereas total annual heating emissions are assumed to be discharged only during winter months.

As a result, contribution of domestic heating to the overall pollution level during the winter months has been calculated as 74%, 45% and 77% for SO_2, NO_x and SPM respectively. This implies that during winter 1991-1992, on the long term average basis, domestic heating contributed about 138$\mu g/m^3$ of SO_2, 56$\mu g/m^3$ of NO_x and 91$\mu g/m^3$ of SPM (see Table 5.8) to the measured concentration levels in the city (which were previously presented in Table 3.5).

In Table 5.8 measurement results of average SO_2, SPM and NO_x concentrations during 1991-1992 winter season and the estimated concentrations of those parameters in the case of electricity use for domestic heating have been given. According to the table estimated GLCs of SO_2 for each power plant alternative (located in Ankara as a hyphotetical case) are below the 1991-1992 winter season measurements. For the parameter of NO_x estimated GLC is also lower compared to the measurement results. NO_x was measured as 125 $\mu g/m^3$ and it has been estimated as 78 and 76 $\mu g/m^3$ for the alternatives of CTPP and NGCC respectively. For the parameter of SPM, estimated GLC, 174 $\mu g/m^3$, for the CTPP (uncontrolled) alternative is higher compared to the measurement results, which was 118 $\mu g/m^3$. However, since new facilities like thermal power plants have to be in compliance with the stack gas effluent standards, they have to be equipped with proper treatment systems like ESP. Annual average GLCs originating from the CTPP alternative equipped with ESP is estimated as 29 $\mu g/m^3$ which is very low compared to the measurement results.

A simple comparison of the measurements with the simulation results summarized in Table 5.8 and presented in detail in Table 5.5 and 5.6 shows that even a CTPP located inside the city of Ankara would lead to much lower long term average GLC values as opposed to the current status.

On the other hand, simulation results concerning short term GLCs, as daily average and maximum hourly, should be approached with a caution as no building downwash effect has been taken into account in these hypothetical studies which can increase the maximum hourly GLCs up to an order of magnitude in some extreme cases. However, even an order of magnitude increase in hourly maximum GLCs for a CTPP alternative equipped with proper treatment technology located inside the city of Ankara would not cause exceedence of standards.

Table 5.8 Comparison of measurements with estimated GLCs for electricity use alternatives in Ankara

Parameters	Measurement Results (91-92 winter season) Long Term Average (μg/m³)	Contribution of existing heating systems		Contribution of existing industrial sources and traffic		Total Estimated GLCs with (uncontrolled) CTPP Alternative (μg/m³)	Total Estimated GLCs with (controlled) CTPP Alternative (μg/m³)	Total Estimated GLCs with NGCC Alternative (μg/m³)
		%	GLCs (μg/m³)	%	GLCs (μg/m³)			
SO_2	187	74	138	26	49	75	58	57
NO_x	125	45	56	55	69	78	78	76
SPM	118	77	91	23	27	174	29	27

One of the most important meteorological parameter, affecting the GLCs, is mixing height only within which pollutants are able to be distributed. In Ankara (Keçiören) and in other meteorological stations, mixing height in summer season is around two times that of winter season (see Table 5.9) which implies for the same amount of pollutants two times higher GLCs are expected in winter. However, a careful examination of Table 3.6 in Chapter 3. indicates that in some of the districts of Ankara measured winter/summer concentration ratios are greater than 2.0 implying that factors such as building downwash, low exit velocity and temperature of effluent gases which are in turn unfavouring the dispersion potential do play an important role. Such adverse factors can easily be eliminated in case of a thermal power plant instead of individual domestic heating systems currently used.

Table 5.9 Seasonal mixing heights for the year 1992 at six meteorological stations (m)

Meteorological Stations	Spring	Summer	Fall	Winter
Ankara (Keçiören)	321	382	203	163
Esenboğa	285	302	161	159
Baypazarı	239	279	165	144
Keskin	371	469	254	220
Kızılcahamam	258	316	174	182
Polatlı	323	367	221	200

CHAPTER 6

COST ESTIMATION OF DIFFERENT DOMESTIC HEATING ALTERNATIVES IN ANKARA

The results presented in Chapter 5 strongly suggests that electricity use for domestic heating in Ankara will result in much better air quality levels. However, since the economy is an important factor in the decision making process a simple cost analysis is included below.

6.1 General Cost Estimations

A simplistic cost estimation of different alternatives for domestic heating in Ankara is given in Table 6.1. The parameters taken into consideration are investment cost, cost of fuel consumed and operation and maintenance costs.

In addition, a brief summary of a recent study by Arıoğlu (1995) and following his assumptions a similar calculations are included in Appendix G. The estimations showed that electricity use alternative and the current individual domestic heating systems are of comparable cost despite of the common contradictory thought.

Table 6.1 Calculated investment cost of different domestic heating system alternatives in Ankara

Coal Fired Stoves:

Number of Dwellings in Ankara (winter 1991-1992) : 644,906

1.5 stoves /dwelling = 967,359 stoves (5 years economical life)

Average price of a coal fired stove = 58$

967,359×58$= 56,106,822$ (for 5 years)

56,106,822×4= **224,427,288$** (for 20 years)

Natural Gas Fired Stoves:

Number of Dwellings in Ankara (winter 1991-1992) : 644,906

1 stoves /dwelling = 644,906 (15 years economical life)

Average price of a natural gas fired stove = 1,670$

644,906×1,670$ = 1,076,993,020$ (for 15 years)

56,106,822×4= **1,435,990,693$** (for 20 years)

Coal Fired Boilers in Each Building:

Number of Building in Ankara (winter 1991-1992) : 208,192

Average price of a Boiler = 21,643$

208,192×21,643$= **4,505,899,456$** (20 years economical life)

Natural Gas Fired Boilers in Each Building:

Number of Building in Ankara (winter 1991-1992) : 208,192

Average price of a Boiler = 10,519$

208,192×10,519$= **2,189,971,648$** (20 years economical life)

Electricity Generated by Conventional Coal Fired Plants (1×660[1]):

Investment Cost of 1 kWe(with FGD) =1,128 US$ (Şahin, Bekdemir, 1994)

660 MW_e ×1,128$/$kW_e$= **744,480,000 US$** (20 years economical life)

Electricity Generated by Natural Gas Combined Cycle Plants (1×450[1]):

Investment Cost of 1 kWe = 771 US$ (Şahin, Bekdemir, 1994)

450 MW_e ×770$/$kW_e$= **346,500,000 US$** (20 years economical life)

[1] Generating capacity of the power plant is calculated in Table 4.7

Table 6.2 Calculated fuel cost of domestic heating for different heating system alternatives in Ankara

Coal Fired Stoves	
Total energy required:	$6{,}321.22\times10^{6}$ kWh/year
Efficiency of coal fired stoves:	50%
Lower heat value of fuel:	4000 kcal/kg
Total fuel required:	$2{,}717.64\times10^{6}$ kg/year
Unit fuel price:	65 US$/ton (June 1992)
Total fuel cost:	**=176,646,303 US$/year**
Natural Gas Fired Stoves	
Efficiency of N. gas fired stoves:	81%
Lower heat value of fuel:	8,100 kcal/Nm^3
Total fuel required:	828.42×10^{6} Nm^3/year
Unit Fuel price:	0.285 US$/$Nm^3$(June 1992)
Total Fuel Cost:	**=236,099,700 US$/year**
Coal Fired Boilers	
Efficiency of coal fired boilers:	55%
Lower heat value of fuel:	4,000 kcal/Nm^3
Total fuel required:	$2{,}470.58\times10^{6}$ kg/year
Unit fuel price:	65 US$/ton (June 1992)
Total fuel cost:	**=160,587,700 US$/year**
Natural Gas fired Boilers:	
Efficiency of N. gas fired boilers:	85%
Lower heat value of Fuel:	8,100 kcal/Nm^3
Total fuel required:	789.44×10^{6} Nm^3/year
Unit fuel price:	0.285 US$/$Nm^3$ (June 1992)
Total fuel cost:	**=224,989,425 US$/year**
Conventional Coal Fired Thermal Power Plant	
Unit fuel price:	10.84 US$/ton
Total Fuel Required:	$3{,}405.57\times10^{3}$ ton/year
Total Fuel Cost:	**=36,916,380 US$/year**
Combined Cycle Natural Gas Fired Power Plant	
Unit fuel price:	0.285 US$/$Nm^3$
Total Fuel Required:	$1{,}332.72\times10^{6}$ Nm^3/year
Total Fuel Cost:	**=379,825,200 US$/year**

In Table G.1 operation and maintenance costs of individual domestic heating systems are included implicity in the investment costs following Arıoğlu, 1995. For the power plant alternatives, operation and maintenance costs are calculated by using the values given in Table 6.3.

Table 6.3 Coal technologies and alternatives, cost and performance

Technology	Generating Capacity MW	Fixed O and M Cost US$/kW/year	Variable O and M Cost US$/kWh
Pulverized Coal Power Plant with FGD	500	33	0.38
Natural Gas fired Combined Cycle	500	10	0.32

Source: Şahin, 1995.

CHAPTER 7

DISCUSSION, CONCLUSION AND FUTURE RECOMMENDATIONS

7.1 Discussion and Conclusions

Today, there is a remarkable increase in energy demand in Turkey parallel to the increase in population and standard of life. This energy requirement should preferably be met by national fossil fuels in our country as far as possible rather than the very controversial imported sources which enhances foreign dependency dramatically (see Section 2.2.1.1). However, while using our national fossil fuel sources of which mainly lignites, have high sulphur, ash and water content and lower calorific value, and hence not appropriate to be used in individual domestic heating systems without any fuel pre-treatment.

In order to solve the air pollution problems inherent in many Turkish cities, alternatives such as the use of imported coal and natural gas have been implemented in the past. However, with the increase of urban population those foreign fuel sources will only increase country's foreign dependency in the near future. Hence the use of national sources in the most logical way should be studied carefully. Electricity use generated through in-country resources for domestic heating is a viable option. The results of this study showed that the use of electricity generated through in-country coal resources for domestic heating is a viable option.

In this study it is shown that potential GLCs of SO_2, NO_x and SPM of thermal power plant alternatives are substantially lower compared to the measurements for 1991-1992 winter season (see Table 5.8). By implication, use of electricity energy in Ankara for the future would prove to be the most advantageous alternative as far as air quality impacts are concerned.

In addition from economical point of view, results of the simplistic cost analysis produced comparable values for electricity use alternative and existing systems (see Table 6.1 and 6.2).

7.2 Recommendations for Future Work

In many of Turkish cities, air pollution in winter months have already reached to the critical level. Measures have been taken so far such as cleaner fossil fuel use, are only short term solutions which should be expected to become inefficient in the near future due to the high population increase.

In order to solve the current and potential problems that future holds long term strategies have to be studied on. This study has only attempted to give an insight on the viability of electricity energy use in Ankara for domestic heating with a rather simplistic, yet comprehensive approach as a prelude to more detailed future studies.

To enable similar studies for other cities in Turkey, current status of the urban areas including current energy requirement, future energy requirement, cost and emission characteristics of the current combustion systems, meteorological, topographical and ecological characteristics of the area should be carefully analyzed before deciding on the appropriate long term pollution control and abatement strategies. Therefore there is an extensive gap concerning those data requirements to be fulfilled.

Another important area of study which will prove to be a valuable tool for decision making, is to evaluate target emission values for urban areas to ensure not to violate current and target concentration standard.

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APPENDIX A

ENERGY BUDGET OF TURKEY

Table A.1 The most important energy indicators in Turkey

Commercial Energy Produced	17,739,000 toe[1] (1992)
Commercial Energy Consumed	42,677,000 toe (1992)
Dependency to Foreign Energy	58 %
Primary Energy Production	26,863,000 toe (1993)
Primary Energy Production by Fuels	
Hard Coal	6.4 %
Lignite	36.6 %
Petroleum	15.2 %
Hydraulic	10.8 %
Firewood, Dried dung	29.5 %
Other (Geothermal, Asphaltic)	1.5 %
Primary Energy Consumption	61,018,000 toe (1993)
Primary Energy Consumption by Fuels	
Hard Coal	9.6 %
Lignite	16.87 %
Natural Gas	7.6 %
Petroleum	46.6 %
Hydraulic	4.8 %
Firewood, Dried dung	13 %
Other (Geothermal, Electricity)	1.53 %
Energy Consumption by Sectors in Amount and Percentage (1993)	
Residential and Commercial	17,498,000 toe (36 %)
Industrial	16,526,000 toe (34 %)
Transportation	10,419,000 toe (21 %)
Other (Agricultural and so on)	4,188,000 toe (9 %)
Net Total	48,632,000 toe (100 %)
Primary Energy Consumption	61,018,000 toe
Cycle	20 %
Primary Energy Consumption per Capita	1,019 koe[2]
Commercial Energy Consumption per Capita	717 koe
Commercial Energy Consumption per capita in the World	1,395 koe
Electricity Production by Primary Energy Sources	
Hard Coal	1.796×10^6 ton/year
Lignite	21.963×10^6 ton/year
Natural Gas	10.788×10^6 ton/year
Petroleum	5.174×10^6 ton/year
Thermal	39,856.6 Gwh
Hydraulic	33,950.9 Gwh
Total	73,807.5 GWh
National Electricity Production by Primary Sources in Percentage	
Hard Coal and Lignite	32.4 %
Petroleum	7 %
Natural Gas	14.6 %
Hydraulic	46 %
Electricity Generating Capacity (1992)	17,027 MW
Electricity Produced (1992)	60,338 GWh
Electricity Consumed (1992)	60,591 GWh
National Electricity Consumption per Capita (1992)	1,060 kWh
Electricity Consumption per Capita in the World (1992)	2,188 kWh

[1] ton oil equivalent

[2] kilogram oil equivalent

Source: Arıoğlu, 1995

Table A.1 The most important energy indicators in Turkey (continued)

Expected Energy Supply and Demand and Amount of Consumptions by Sectors for the year of 2000	
Thermal	104,249 GWh
Hydraulic	44,788 GWh
Total (Supply)	149,037 GWh
Demand	130,350 GWh
Stand-by	14 %
Industrial	72,195 GWh
Residential and Commercial	39,326 GWh
Transportation	1,424 GWh
Agricultural	1,427 GWh
Consumption per Capita	1,878 kWh
Amount and Cost of the Primary Energy expected to be Imported for the year of 2000	
Hard Coal	8×10^6 ton/year
Steam Coal	6.5×10^6 ton/year
	(846 Million $) (Cost of Hard Coal included)
Petroleum Products	
Natural Gas	36.5×10^6 ton/year (7.758 Billion $)
Total	125×10^9 m^3/year (1.370 Bilion $)
	9.975 Billion $

APPENDIX B

A RECENT COST ANALYSIS CONDUCTED FOR FLUE GAS TREATMENT OF TURKISH THERMAL PLANTS

A summary of a recent cost analysis conducted for Turkish thermal power plants (TEAŞ, 1996) is presented below (see Table B.1 and B.2). According to this study installation of FGD and ESP systems will prove to be highly efficient in reducing potential emissions (see Figure B.1 and B.2).

Table B.1 Characteristics and economical data on FGD in thermal power plants

Thermal Power Plants	Type of FGD	Efficiency of FGD	Investment Cost		Constant Operational Costs	Variable Operational Costs	Total Operational Costs
		(%)	($/kW)	($/Gj in)	($/kW-m)	($MWh)	($/Gj in)
Yatağan 1-3	Wet	95	165	1.9882	0.56	0.97	0.2115
Kemerköy 1-3	Wet	95	149	1.7954	0.59	1.62	0.2860
Yeniköy 1-2	Wet	95	223	2.5457	0.87	1.62	0.3223
Orhaneli 1	Wet	95	278	3.0854	0.90	0.83	0.2422
Çayırhan 3-4	Wet	95	178	1.9190	0.76	1.07	0.2352
Kangal 3	Wet	95	241	2.3690	0.93	1.72	0.2962
Afşin-Elbistan A 5-6	Wet	95	148	1.3141	0.63	1.46	0.2040
Soma-B 1-6	Dry	70	96	1.0305	0.46	1.73	0.2441
L-340	Wet	95	191	2.1198	0.77	1.77	0.3115
L-300	Wet	95	213	2.4315	0.84	1.08	0.2649
L-150	Wet	95	287	3.4583	1.09	1.04	0.3235
HC-30	Wet	90	186	2.1233	0.81	0.16	0.1655
CIMP	Wet	90	159	1.8655	0.54	0.16	0.1205

Table B.2 Characteristics and economical data on ESP in thermal power plants

Thermal Power Plants	Efficiency of ESP	Investment Cost		Constant Operating Costs	Variable Operating Costs	Total Operating Costs
	(%)	($/kW)	($/Gj in)	($/kW-m)	($MWh)	($/Gj in)
Yatağan 1-3	99.4	-	-	0.093	0.047	0.023
Afşin-Elbistan 1-4	99.0	-	-	0.015	0.171	0.016
Yeniköy 1-2	99.4	-	-	0.017	0.098	0.013
Kemerköy 1-3	99.4	-	-	0.029	0.054	0.011
Seyitömer 1-4	98.0	-	-	0.006	0.136	0.015
Soma-A	99.0	-	-	0.104	0.075	0.022
Soma-B 1-6	99.0	-	-	0.006	0.434	0.042
Tunçbilek A-B	98.0	-	-	0.091	0.100	0.028
Çayırhan 1-2	99.6	-	-	0.039	0.065	0.013
Kangal 1-2	98.0	-	-	0.039	0.025	0.008
Orhaneli 1	99.8	-	-	0.001	0.091	0.009
Çatalağzı-B 1-2	99.0	-	-	0.054	0.272	0.037
Çayırhan 3-4	99.5	54.63	0.5890	0.039	0.065	0.013
Kangal 3	99.5	72.27	0.7104	0.039	0.025	0.008
Afşin-Elbistan A5-6	99.5	56.33	0.5001	0.015	0.171	0.016
L-340	99.5	63.99	0.7101	0.049	0.060	0.015
L-300	99.5	67.75	0.7734	0.045	0.060	0.014
L-150	99.5	67.71	0.8159	0.045	0.050	0.014
HC-30	99.5	64.48	0.7361	0.049	0.060	0.015
CIMP	99.5	59.37	0.6965	0.066	0.060	0.019

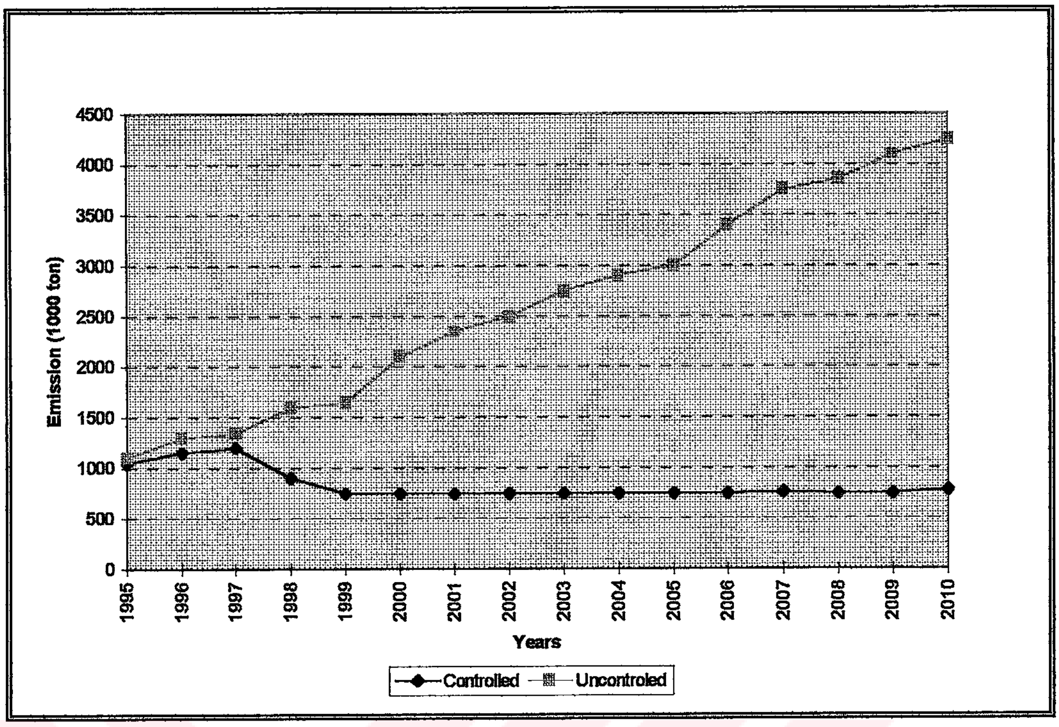

Figure B.1 SO_2 Emissions from thermal power plants by years

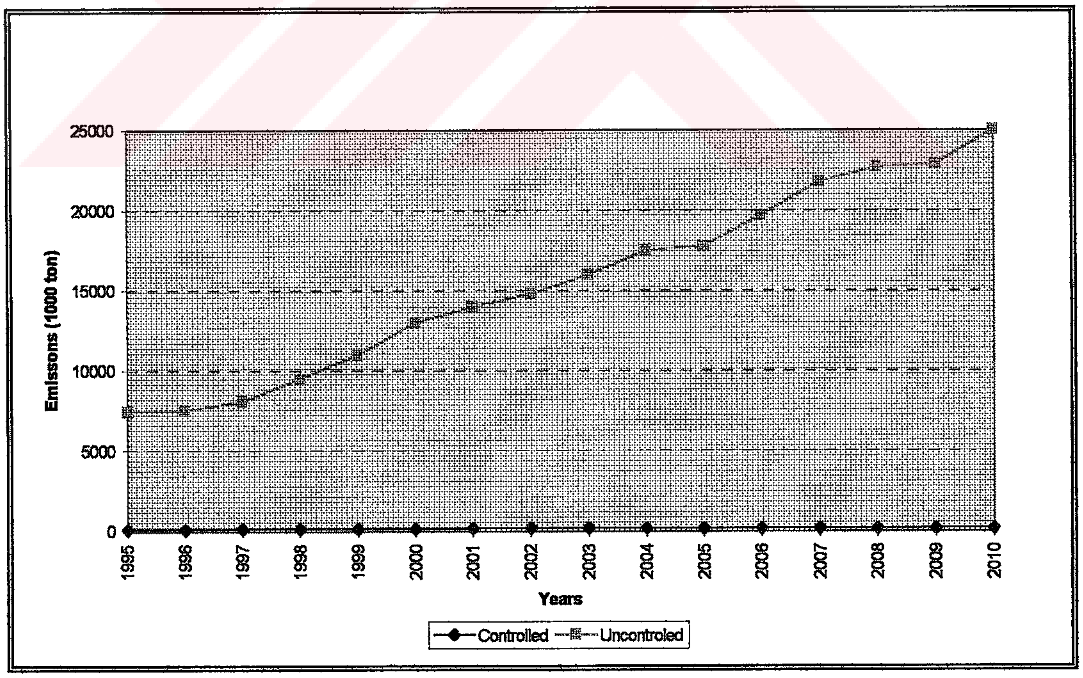

Figure B.2 Particulate emissions from thermal power plants by years

APPENDIX C

MITIGATION MEASURES FOR THERMOELECTRIC PROJECTS

Potential negative impacts and mitigating measures for thermoelectric projects and electric power transmission systems are presented in Table C.1.

Table C.1 Potential negative impacts and mitigating measures for thermoelectric projects

Potential Negative Impacts	Mitigating Measures
1. Air emission effects to human health, agriculture, and native wildlife and vegetation.	• Locate facility away from sensitive air quality receptor • Design higher stacks to reduce ground level concentrations. • Use cleaner fuels (e.g., low sulphur coal) • Install air pollution control equipment.
2. Thermal shock to aquatic organisms.	• Use alternative heat dissipation design (e.g., closed cycle cooling). • Dilute thermal condition by discharging water into larger receiving water body. • Install mechanical diffusers. • Cool water on-site in holding pond prior to discharge,. • Explore opportunities to use waste heat.
3. Vegetation removal and habitat loss.	• Select alternative site or site layout to avoid loss of ecological resources. • Restore or create similar vegetation or habitats.
4. Avian hazards from stacks, towers and transmission lines.	• Site stacks and tower away from flyways. • Install deflectors, lights and other visible features.
5. Human population displacement	• Select alternative site or site layout to avoid displacement. • Involve affected parties in the resettlement planning and program. • Constuct socially and culturally acceptable settlements/infrastructure development.
6. Modification of historically or archaeologically structures or lands (e.g., churches, temples, mosques, cemeteries).	• Select alternative site or site layout. • Develop and implement "chance find" procedures to recover, relocate or restore structures. • Fence or constuct other barriers to protect structures or lands.
7. Worker exposure to dust from ash and coal.	• Provide dust collector equipment. • Maintain dust levels ≤ $10 mg/m^3$. • Monitor for free silica content. • Provide dusk musks when levels are exceeded.
8. Worker exposure to toxic gases leaking from broilers.	• Maintain boilers properly. • Monitor concentrations will levels not to exceed: SO_2 5 ppm CO 50 ppm NO_2 5 ppm
9. Loss of land use and population relocation due to placement of towers and substations.	• Select right-of-way (ROW) to avoid important social, agricultural, and cultural resources. • Utilize alternative tower designs to reduce ROW width requirements and minimize land use impacts. • Adjust the length of the span to avoid site-specific tower pad impacts.
10. Avian hazards from transmission lines and towers.	• Select ROW to avoid important bird habitats and flight routes. • Install towers and lines to minimize risk for avian hazards. • Install deflectors on lines in areas with potential for bird collision.
11. Aircraft hazards from transmission lines and towers.	• Select ROW to avoid airport flight paths. • Install markers to minimize risk of low-flying aircraft.

Source: World Bank, Environmental Department, 1992

APPENDIX D

URBAN AIR QUALITY STATUS IN TURKEY (MEASUREMENTS)

SO_2 and PM concentrations have been measured by Ministry of Health and the results have been published by the State Institute of Statistics since 1990. Winter and summer season SO_2 and PM average concentrations in provinces for the last six years are given in Table C.1 and Table C.2.

Sulphur Dioxide

In Table C.1 measured maximum and minimum and average SO_2 concentrations in Turkish cities between 1990-1995 are given for winter and summer seasons. In the same table, number of days exceeding the STS of Turkish Air Quality Protection Regulation; ratio of summer and winter concentrations and the trend between 1990 and 1995 are shown for each city. As it can be seen from the table, average SO_2 concentrations during winter season are regularly above the LTS in Erzurum, Kütahya, Eskişehir, Sivas, Çorum, Çankırı, İstanbul, Konya, Diyarbakır, Kırıkkale, Kahramanmaraş, Kayseri, Kocaeli, Çanakkale, Bursa, Adıyaman, Malatya, Tokat, Nevşehir, Balıkesir, Kırşehir, Yozgat, Gaziantep and İzmir.

For the same cities daily SO_2 averages have frequently exceeded STS. Obviously, in these 24 cities especially during winter season air pollution is a very important problem.

Obviously, winter/summer concentration ratios result in a number bigger than 1 in all cities, as the meteorological conditions unfavour the pollution dispersion in winter months. However, the ratio between winter and summer concentrations are rather big in many Turkish cities, implying the important contribution of domestic heating. As can be seen in Table C.1, there are only a few provinces in which winter concentrations are lower than that of two times summer concentrations. These cities are Gaziantep, İzmir, Van, Mardin, Kırklareli, Bilecik, Hatay, İçel and Kars. Among them, Gaziantep is industrialized region, İzmir and İçel have very mild winters, Mardin and Kars have missing data, therefore it is rather difficult to comment on these latter cities. On the other hand, in many Turkish cities winter/summer concentration ratios are equal or more than 4. These cities are Erzurum, Kütahya, Eskişehir, Sivas, Çorum, Muğla, Konya, Bayburt, Diyarbakır, Kahramanmaraş, Çanakkale, Malatya, Kırşehir, Ağrı, Yozgat, Edirne, Sakarya, Afyon, Elazığ, Burdur, Erzincan and Siirt. Among them Eskişehir, Bayburt, Malatya and Konya are especially remarkable.

Suspended Particulate Matter

Winter season SPM concentrations between 1990-1995 are given in Table C.2. A similar evaluation for SPM concentrations shows that the share of the domestic heating on the SPM concentration is not as important as the SO_2 concentrations. The first group of cities under risk are only Diyarbakır, Sivas, Erzurum and Zonguldak. Additionally, there is an increase trend in Erzurum and Zonguldak and a decline in Diyarbakır and Sivas. Except these four cities, SPM concentrations varies between 100 and 150 $\mu g/m^3$ in Tokat, Adıyaman, Muş, Afyon, Kahramanmaraş, Kocaeli, İzmir, Rize, İstanbul, Kütahya, Kayseri, Antalya, Erzincan, Bursa, Konya, Van and Ankara during winter season. In addition there has been a 10% increase observed in Afyon and Rize.

Nitrogen Oxides and Ozone

NO_x, being a primary pollutant originating from all combustion activities have certain health effects itself. It also causes O_3 and photochemical smog formation in urban atmospheres, consequently bring some secondary effects as well. As shown in Chapter 3 in Table 3.1, ambient NO_x standards are stricter in comparison to SO_x and SPM.

Recent NO_x measurements conducted in different locations in Turkey are given in Table C.3. Results show that monthly averages of NO concentrations in Erzurum is between 70 and 153 $\mu g/m^3$ and that of NO_2 concentrations is between 110-188 $\mu g/m^3$ in winter season of 1994. There are NO_x measurements in Bursa for January and March in 1996. The results of these measurements shows that both NO and NO_2 concentrations is around 13 $\mu g/m^3$. Similarly, recent O_3 measurements, carried out in Antalya since November 1994 and in Amasra for April-June of 1995, are summarized in Table C.4. Results show that concentrations are around 30 ppb in rural areas. Bearing in mind, long term ambient air quality standard for O_3 is 110 ppb in Turkey and 120 ppb in USA, it would not be a an overstatement to assume urban O_3 concentrations in Turkish cities has already exceeded the standards in summer months.

Table D.1 SO_2 concentrations in summer and winter seasons in provinces, $\mu g/m^3$

	Percentage of Sum/Win Concentrations	SUM	WIN		SUM	WIN		SUM	WIN		SUM	WIN		SUM	WIN	
PROVINCES	1990-1995	Avg90	Avg9091	Win/Sum	Avg91	Avg9192	Win/Sum	Avg92	Avg9293	Win/Sum	Avg93	Avg9394	Win/Sum	Avg94	Avg9495	Win/Sum
ADANA	3.2	13	37	3	17	48	3	12	43	4	13	52	4	14	50	4
ADIYAMAN	3.4	44	193	4	68	211	3	72	220	3	71	193	3	39	..	..
AFYON	4.4	29	114	4	36	..	..	30	..	..	34	175	5	33	157	5
AMASYA	2.3	34	63	2	29	51	2	33	51	2	36	66	2	18	112	6
ANKARA	3.4	59	218	4	43	187	4	..	130	..	29	90	3	24	79	3
ANTALYA	3.1	18	79	4	20	47	2	20	100	5	24	43	2	15	44	3
AYDIN	3.0	24	63	3	21	64	3	19	65	3	24	66	3	18	60	3
BALIKESİR	2.9	50	101	2	63	131	2	79	..	..	..	225	..	54	220	4
BİLECİK	1.8	46	110	2	61	128	2	53	53	1	27	33	1	11	44	4
BİNGÖL	2.2	70	139	2	60	156	3	42	90	2	34	71	2	36	71	2
BOLU	2.3	47	87	2	42	..	..	..	148	..	67	136	2	37	93	3
BURDUR	4.0	..	98	..	21	94	4	32	129	4	30	143	5	29	153	5
BURSA	3.4	73	329	5	79	324	4	70	172	2	80	150	2	43	85	2
ÇANAKKALE	5.1	..	..	..	51	248	5	35	178	5	34	167	5	40	104	3
ÇORUM	4.7	72	..	..	47	195	4	46	342	7	84	356	4	61	267	4
DENİZLİ	2.3	68	103	2	52	135	3	48	162	3	..	..	..	..	134	..
DİYARBAKIR	5.6	60	285	5	41	326	8	40	276	7	42	169	4	31	133	4
EDİRNE	4.1	45	122	3	31	119	4	40	185	5	36	153	4	31	174	6
ELAZIĞ	3.7	55	242	4	25	108	4	16	50	3	15	156	10	52	50	1
ERZİNCAN	4.7	27	120	4	23	76	3	12	64	5	11	76	7	9	67	7
ERZURUM	5.1	32	262	8	45	307	7	57	379	7	110	404	4	70	262	4
ESKİŞEHİR	6.6	56	308	6	48	334	7	43	300	7	41	306	7	42	280	7
GAZİANTEP	1.8	70	137	2	94	171	2	..	..	..	91	163	2	101	154	2
GİRESUN	3.3	23	74	3	21	70	3	26	103	4	29	90	3	28	81	3

Table D.1 SO_2 concentrations in summer and winter seasons in provinces, µg/m^3 (continued)

	Percentage of Sum/Win Concentrations	SUM	WIN		SUM	WIN		SUM	WIN		SUM	WIN		SUM	WIN	
PROVINCES	1990-1995	Avg90	Avg9091	Win/Sum	Avg91	Avg9192	Win/Sum	Avg92	Avg9293	Win/Sum	Avg93	Avg9394	Win/Sum	Avg94	Avg9495	Win/Sum
HATAY (İskenderun)	1.3	52	..	..	45	80	2	68	76	1	64	73	1	58	75	1
ISPARTA	3.0	44	104	2	44	134	3	35	149	4	47	149	3	46	127	3
İÇEL	1.9	21	36	2	47	..	..	..	..	..	..	..	..	..	..	..
İSTANBUL	2.7	111	315	3	161	379	2	132	290	2	..	253	..	71	189	3
İZMİR	1.8	64	112	2	58	170	3	124	219	2	107	140	1	70	124	2
KARS	1.2	52	47	1	36	53	1	30	..	..	..	..	..	..	..	..
KASTAMONU	2.8	40	185	5	..	136	..	74	152	2	47	124	3	29	82	3
KAYSERİ	3.4	58	254	4	63	249	4	62	190	3	..	202	..	60	126	2
KIRKLARELİ	1.0	90	132	1	121	78	1	51	89	2	..	73	..	60	50	1
KIRŞEHİR	5.1	44	160	4	35	166	5	31	160	5	28	187	7	34	193	6
KOCAELİ	3.8	93	305	3	68	290	4	42	208	5	34	94	3	29	131	5
KONYA	5.7	48	415	9	44	199	5	30	210	7	55	252	5	39	187	5
KÜTAHYA	5.2	54	283	5	62	384	6	62	369	6	73	300	4	53	236	4
MALATYA	7.0	..	339	..	30	196	7	38	202	5	23	126	5	20	127	6
MANİSA	3.8	27	96	4	29	115	4	27	122	5	27	95	4	26	92	4
KAHRAMANMARAŞ	4.0	46	167	4	50	255	5	56	253	5	86	267	3	56	201	4
MUŞ	3.6	23	79	3	30	85	3	37	64	2	27	93	3	33	207	6
NEVŞEHİR	3.1	47	230	5	73	187	3	73	237	3	..	122	..	35	143	4
NİĞDE	2.4	54	115	2	55	119	2	45	128	3	49	88	2	36	124	3
ORDU	2.0	20	25	1	18	42	2	14	42	3	25	44	2	19	40	2
RİZE	2.0	25	56	2	30	72	2	34	80	2	42	96	2	52	68	1
SAKARYA	5.0	51	187	4	..	221	..	..	130	..	..	78	..	..	103	..
SAMSUN	2.0	67	187	3	51	84	2	50	106	2	40	90	2	40	58	1
SİİRT	5.2	15	59	4	11	71	6	12	88	7	..	52	..	11	32	3

Table D.1 SO_2 concentrations in summer and winter seasons in provinces, $\mu g/m^3$ (continued)

	Percentage of Sum/Win Concentrations	SUM	WIN		SUM	WIN		SUM	WIN		SUM	WIN		SUM	WIN	
PROVINCES	1990-1995	Avg90	Avg9091	Win/Sum	Avg91	Avg9192	Win/Sum	Avg92	Avg9293	Win/Sum	Avg93	Avg9394	Win/Sum	Avg94	Avg9495	Win/Sum
SİNOP	2.3	..	27	..	3	19	6	3	29	10	11	34	3	..	31	..
SİVAS	5.2	68	402	6	56	278	5	88	337	4	64	328	5	48	173	4
TEKİRDAĞ	3.7	30	117	4	26	96	4	..	157	..	..	57	..	5	174	35
TOKAT	2.9	..	227	..	73	203	3	74	192	3	67	161	2	33	133	4
TRABZON	2.8	15	64	4	29	68	2	27	95	4	33	89	3	31	61	2
TUNCELİ	2.0	17	23	1	14	..	..	14	23	2	17	20	1	8	31	4
UŞAK	2.6	51	118	2	44	109	2	40	98	2	51	118	2	44	150	3
VAN	1.7	78	..	..	37	56	2	59	101	2	..	..	..	..	..	..
YOZGAT	4.1	47	186	4	38	165	4	54	164	3	28	172	6	35	139	4
ZONGULDAK	1.5	60	89	1	48	129	3	123	..	..	20	74	4	34	73	2
KIRIKKALE	3.6	42	226	5	51	204	4	64	241	4	80	304	4	86	211	2

Source: State Institute Statistics (DIE), 1995

Table D.2 PM concentrations in summer and winter seasons in provinces, $\mu g/m^3$

	Percentage of Sum/Win Concentrations	SUM	WIN		SUM	WIN		SUM	WIN		SUM	WIN		SUM	WIN	
PROVINCES	1990-1995	Avg90	Avg9091	Win/Sum	Avg91	Avg9192	Win/Sum	Avg92	Avg9293	Win/Sum	Avg93	Avg9394	Win/Sum	Avg94	Avg9495	Win/Sum
ADANA	1.8	34	38	1	23	57	2	29	58	2	31	63	2	30	53	2
ADIYAMAN	3.5	37	140	4	40	134	3	43	152	4	46	138	3	26	..	..
AFYON	3.8	32	111	3	38	..	..	30	..	..	35	158	5	33	140	4
AMASYA	2.9	18	40	2	12	22	2	10	25	3	17	55	3	12	62	5
ANKARA	2.1	58	107	2	56	118	2	..	97	..	42	108	3	34	77	2
ANTALYA	3.2	34	136	4	37	93	3	32	133	4	37	116	3	28	80	3
AYDIN	2.8	26	65	3	24	66	3	23	66	3	24	63	3	18	56	3
BALIKESİR	2.7	25	65	3	44	72	2	..	..	..	..	82	..	27	105	4
BİLECİK	1.8	24	38	2	23	49	2	21	35	2	22	44	2	17	31	2
BİNGÖL	3.3	33	112	3	37	154	4	32	75	2	21	48	2	21	80	4
BOLU	2.9	36	83	2	28	..	..	..	117	..	34	74	2	15	58	4
BURDUR	2.8	..	55	..	11	48	4	27	65	2	17	71	4	21	58	3
BURSA	3.2	49	139	3	51	136	3	20	99	5	38	97	3	18	69	4
ÇANAKKALE	4.3	..	..	..	13	57	4	9	28	3	9	45	5	8	16	2
ÇORUM	2.5	57	..	..	24	60	3	..	85	..	29	91	3	17	59	3
DENİZLİ	2.9	20	78	4	28	100	4	31	102	3	..	..	..	..	118	..
DİYARBAKIR	5.6	40	201	5	39	278	7	39	276	7	41	176	4	33	135	4
EDİRNE	4.6	9	49	5	16	54	3	12	57	5	9	41	5	8	55	7
ELAZIĞ	5.4	23	178	8	22	106	5	15	44	3	13	65	5	11	33	3
ERZİNCAN	5.8	24	134	6	18	156	9	12	80	7	20	98	5	18	89	5
ERZURUM	4.7	27	141	5	32	180	6	40	225	6	67	260	4	46	173	4
ESKİŞEHİR	2.5	25	55	2	25	60	2	27	70	3	23	61	3	29	81	3
GAZİANTEP	2.9	32	77	2	45	103	2	..	..	..	46	101	2	52	99	2
GİRESUN	2.1	23	58	3	17	54	3	21	58	3	23	61	3	21	71	3

Table D.2 PM concentrations in summer and winter seasons in provinces, $\mu g/m^3$ (continued)

	Percentage of Sum/Win Concentrations	SUM	WIN		SUM	WIN		SUM	WIN		SUM	WIN		SUM	WIN	
PROVINCES	1990-1995	Avg90	Avg9091	Win/Sum	Avg91	Avg9192	Win/Sum	Avg92	Avg9293	Win/Sum	Avg93	Avg9394	Win/Sum	Avg94	Avg9495	Win/Sum
HATAY (İskenderun)	1.2	42	..	..	74	88	1	81	81	1	71	77	1	58	66	1
İSPARTA	2.8	27	68	3	34	102	3	24	75	3	26	61	2	18	56	3
İÇEL	3.5	16	31	2	20	..	..	..	..	..	..	..	..	..	..	..
İSTANBUL	2.0	63	151	2	81	141	2	56	114	2	..	100	..	43	83	2
İZMİR	1.7	59	82	1	53	157	3	113	165	1	69	116	2	50	87	2
KARS	1.0	53	45	1	18	22	1	22	..	..	..	..	..	..	..	..
KASTAMONU	3.1	31	79	3	..	65	..	25	73	3	23	105	5	21	70	3
KAYSERİ	3.3	29	118	4	35	110	3	25	106	4	..	153	..	46	75	2
KIRKLARELİ	1.4	35	71	2	54	58	1	33	58	2	..	50	..	44	42	1
KIRŞEHİR	2.0	25	78	3	31	77	2	27	73	3	32	78	2	26	62	2
KOCAELİ	2.6	62	150	2	53	148	3	44	102	2	37	119	3	43	95	2
KONYA	5.2	20	154	8	28	92	3	17	82	5	15	98	7	17	87	5
KÜTAHYA	2.3	52	111	2	45	125	3	55	123	2	55	103	2	33	88	3
MALATYA	5.5	..	179	..	18	95	5	21	92	4	16	74	5	17	56	3
MANİSA	3.2	22	65	3	23	85	4	21	70	3	22	70	3	23	65	3
KAHRAMANMARAŞ	3.2	23	130	6	29	130	4	30	123	4	64	153	2	59	94	2
MUŞ	3.5	29	106	4	36	113	3	47	92	2	30	103	3	37	219	6
NEVŞEHİR	2.0	36	100	3	42	76	2	42	95	2	..	56	..	23	44	2
NİĞDE	2.6	19	47	2	18	45	3	17	42	2	14	42	3	12	29	2
ORDU	2.2	18	40	2	21	19	1	15	53	4	32	62	2	24	53	2
RİZE	2.2	34	94	3	40	91	2	45	122	3	57	161	3	84	113	1
SAKARYA	4.3	22	69	3	..	92	..	24	66	3	12	40	3	6	68	11
SAMSUN	1.9	37	89	2	25	31	1	22	50	2	20	35	2	18	31	2
SİİRT	7.7	9	62	7	7	61	9	7	82	12	..	54	..	10	50	5

Table D.2 PM concentrations in summer and winter seasons in provinces, $\mu g/m^3$ (continued)

	Percentage of Sum/Win Concentrations	SUM	WIN		SUM	WIN		SUM	WIN		SUM	WIN		SUM	WIN	
PROVINCES	1990-1995	Avg90	Avg9091	Win/Sum	Avg91	Avg9192	Win/Sum	Avg92	Avg9293	Win/Sum	Avg93	Avg9394	Win/Sum	Avg94	Avg9495	Win/Sum
SİNOP	1.8	20	22	1	8	25	3	10	29	3	18	21	1	6	14	2
SİVAS	2.8	60	250	4	96	222	2	78	208	3	73	211	3	66	125	2
TEKİRDAĞ	1.7	34	61	2	36	63	2	..	64	..	50	44	1	13	49	4
TOKAT	3.1	51	187	4	50	140	3	45	145	3	50	134	3	33	97	3
TRABZON	3.0	23	90	4	29	72	2	30	94	3	30	86	3	24	63	3
TUNCELİ	2.8	14	48	3	16	..	..	22	46	2	22	27	1	2	..	..
UŞAK	2.7	29	89	3	27	67	2	22	65	3	30	71	2	24	66	3
VAN	2.0	81	..	..	33	98	3	44	135	3	..	..	..	..	..	..
YOZGAT	3.7	19	76	4	19	65	3	20	57	3	12	72	6	16	47	3
ZONGULDAK	2.7	47	130	3	48	174	4	121	166	1	36	159	4	46	156	3
KIRIKKALE	3.7	41	100	2	15	64	4	22	79	4	15	109	7	20	71	4

Source: State Institute Statistics (DİE), 1995

Table D.3 NO_x Concentrations measured in Erzurum and Bursa

Months	Erzurum (1994)		Bursa (1996)	
	NO ($\mu g/m^3$)	NO_2 ($\mu g/m^3$)	NO ($\mu g/m^3$)	NO_2 ($\mu g/m^3$)
January	153	185	11	14
February	153	188		
March	86	110	14	12
November	70	167		

Source: Tuncel, 1995

Table D.4 O_3 Concentrations measured in Amasra and Antalya

Year	Months	Amasra ppb	Antalya ppb
1	September		22
9 9	November		26
4	December		21
	January		21
1	February		24
	March		30
	April	42	36
9	May	39	35
	June	32	31
	July		39
9	August		29
	September		31
	October		29
5	November		22
	December		16

Source: Tuncel, Environmental Eng. Dep. of METU, 1995.

APPENDIX E

EUROPEAN AMBIENT AIR QUALITY STANDARDS

In a recent publication of Economic Comission for Europe, strategies and policies for air pollution has been summarised (ECE, 1995). According to this document, policy measures should be grouped into four categories: regulatory measures, economic instruments, measures related to technology, and the monitoring and assessment of effects. Ambient air quality standards or target levels frequently serve as a reference base for other standards (emissions, fuel quality, control technology) designed to achieve a given desirable level of air quality in the context of regulatory measures. Therefore in many circumstances, ambient air quality standards serve as a locomotive to implement other control mechanisms. A summary of ambient air quality standards effective in various European countries and United States are given in Table E.1 which can be compared with currently effective Turkish standards.

Table E.1 European ambient air quality standards (ECE/EB.AIR/44, 1995)

Country	Sulphur dioxide ($\mu g/Nm^3$)			Nitrogen dioxide ($\mu g/Nm^3$)			Particulates ($\mu g/Nm^3$)			Ozone ($\mu g/Nm^3$)		
	Short Term	Medium Term[1]	Long Term	Short Term	Medium Term[1]	Long Term	Short Term	Medium Term	Long Term[5]	Short Term[3]	Medium Term	Long Term
Austria	500[2]	200	-	200[2]	-	-	-	200[2]	-	-	-	-
Belgium	-	400	250[2]	-	150	200[3]	-	-	80[1]	240	110[4]	-
Bulgaria	500[2]	150	50[5]	200[2]	100	50[5]	500[2]	250[1]	150[5]	160	50[1]	30[5]
Canada	900[3]	300	60[5]	400[3]	200	100[5]	-	120[1]	70[5]	160	50[1]	30[5]
Cyprus	250[3]	-	80[5]	400[3]	150	-	250[3]	250[1]	150[5]	175	100[1]	-
Czec Republic	500[2]	150	60[5]	200[2]	100	80[5]	500[2]	150[1]	60[5]	-	160[4]	-
Denmark	-	250	80[1]	200[3]	-	-	-	300[1]	150[5]	180	110[4]	-
Finland	500[3]	200	40[5]	300[3]	150	-	-	150[1]	60[5]	-	-	-
Germany	EEC[6]	EEC	EEC	EEC	EEC	80[5]	EEC	EEC	EEC	EEC	EEC	EEC
Greece	-	250	80[1]	-	-	200[3]	-	250[1]	80[1]	-	-	-
Italy	125[1]	130	80[1]	-	200[3]	200[3]	-	90[1]	150[1]	180	-	-
Netherlands	830[3]	500	75[1]	150[3]	-	135[3]	-	150[1]	75[1]	240	160[4]	100[7]
Norway	400[8]	90	40[9]	100[3]	75	50[8]	-	70	40[8]	100	80[4]	-
Poland	600[2]	200	32	500[2]	150	50	-	120	50	100[2]	30[1]	-
Romania	750[2]	250	60	30[2]	100	60	500[2]	150	75	100[2]	30[1]	-
Slovakia	500	150	60	200[2]	100	80	500[2]	150	60	150	100[4]	120[5]
Sweden	200[3]	100	50	110[3]	75	50	-	90	40	120	-	-
Switzerland	100[2]	100	30	100[2]	80	30	-	150	70	100	-	-
Ukraine	-	50	-	-	40	-	-	150	-	-	30[1]	-
United Kingdom	-	-	EEC[6]	-	-	EEC	-	-	EEC	EEC	EEC	-
United States	-	365	80	-	-	100	-	150	50	235	-	-
Yugoslavia	350[3]	150	50	150[3]	85	60	150[3]	50	50	-	-	-

1 24 hours averaging time
2 30 minutes averaging time
3 1 hour averaging time
4 8 hours averaging time
5 1 year averaging time
6 As in related EEC directive
7 seasonal average
8 15 minutes averaging time
9 6 minutes averaging time

APPENDIX F

A RECENT EMISSION INVENTORY CONDUCTED FOR ANKARA

An emission inventory conducted by Atımtay (1993) provides a useful insight into Ankara's current energy use portfolio and related emissions. Table F.1 presents the total energy use in Ankara by sources and sectors, and Table F.2 emissions. Figure E.1 shows the emission distribution graphically.

Table F.1 Total amount of energy used in Ankara by sources and sectors

Sources	Fuel Consumed (ton/year)	Total Energy (kcal/year)	Usage (%)
Residential and Commercial		**$9{,}178\times10^9$**	**78.1**
Coal	732,917	$4{,}382\times10^9$	
Natural Gas (10^3 Nm^3)	402,677	$3{,}262\times10^9$	
Fuel-Oil (for boilers)	153,436	$1{,}534\times10^9$	
Industrial		**787×10^9**	**6.7**
Coke, Hard Coal	6,835		
Lignite (Tunçbilek)	31,970		
Fuel-Oil No.6	47,470		
Natural Gas (Nm^3)	95,130		
Motorin	12,742		
Traffic		**$1{,}792\times10^9$**	**15.2**
Petrol	92,366	$1{,}108\times10^9$	
Diesel	62,250	684×10^9	

Table F.2 Total amount of emissions by sources and sectors in Ankara (ton/year)

Sources	Fuel Consumed	CO	NO_x	C_mH_n	SO_2	Particulate Matter	Lead
Residential and Commercial		**24,465**	**2,531**	**27,028**	**7,006**	**5,762**	**-**
Coal							
used in stoves	472,300	17,950	1,086	94	1,889		
used in Boilers	260,617	4,092	425	15,142	1,200		
Natural Gas (10^3 Nm^3)	402,677	2,375	330	7,006	7		
Fuel-Oil (for boilers)	153,436	48	690	4,786	3,910		
Industrial		**10,965**	**365**	**3,492**	**4,139**	**3,265**	**-**
Coke, Hard Coal	6,835						
Lignite	31,970						
Fuel-Oil No.6	47,470	10,965	365	3,492	4,139	3,265	-
Natural Gas (Nm^3)	95,130						
Motorin	12,742						
Traffic	**154,616**	**19,389**	**5,947**	**3,276**	**808**	**108**	**13**
Petrol	92,366	17,930	2,305	2,269	473	38	13
Diesel	62,250	1,459	3,642	1,007	335	70	

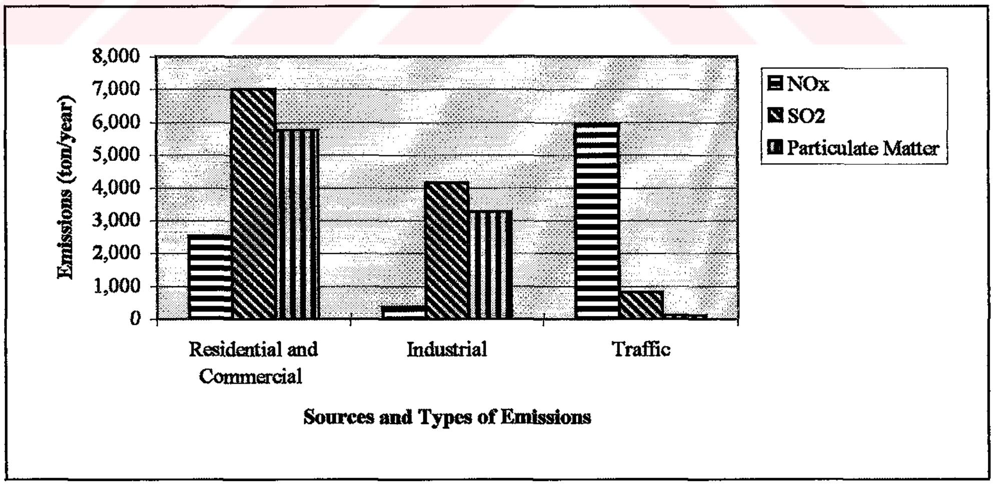

Figure F.1 Amount of emissions by sectors

APPENDIX G

COST ESTIMATION FOR DIFFERENT DOMESTIC HEATING ALTERNATIVES

In a recent study by Arıoğlu (1995) amount and cost of fuel used in lignite fired stoves, LPG fired stoves and natural gas fired stoves have been calculated (see Table G.1). Following his assumptions amount and cost of fuel used in imported fired boilers, natural gas fired boilers and cost of heating by electricity have been calculated (see Table G.2).

Additionally, in an earlier study by Uluğ (1987) a similar cost analysis concerning electricity use had been proved to be a viable option for future (see Table G.3). In this study it was stated that "Although the use of electricity for domestic heating seems to be difficult today, in the years of 2000 by the technological improvements on the energy transmission and isolated transmission centers it may become a good alternative for domestic heating. By considering current air pollution problems in cities, electricity use has to be initiated step by step from now on".

Table G.1 Calculated cost of fuel in domestic heating systems (Arıoğlu, 1995)

ASSUMPTIONS:	
• Area heated	$A = 50 m^2$
• Number of days used per year	t_y = 180 days
• Number of hours use per day	t_g = 10 hours
• Thermal power of the stove	Q_b = 5,000 kcal/hour
• Thermal efficiencies of different stoves	
• Coal Fired Stoves	
• LPG Fired Stoves	$\eta_{bl} = 70\%$
• Natural Gas Fired Stoves	$\eta_{bl} = 95\%$
• Lower heat value and cost of the Lignites	$\eta_{bl} = 85\%$
• Lower heat value and cost of the LPG	LHV_l = 3,500 kcal/kg (in original)
• Lower heat value and cost of the Natural Gas	m_l =1,900,000 TL/ton=1,900TL/kg
	LHV_k = 11,200 kcal/kg
	m_k =15,083 TL/kg
	LHV_d = 8,250 kcal/kg
	m_d =6,480 TL/kg

- Annual Cost of Fuel Consumption in the Stoves

$$M_y = \frac{Q_b^{(kcal/hour)}}{\eta_b \times LHV^{(kcal/kg)}} \times t_g^{(hours/day)} \times t_y^{(days/year)} \times m (TL/year)$$

- Annual Fuel Consumption in the Stoves

$$T_y = \frac{Q_b^{(kcal/hour)}}{h_b \times LHV^{(kcal/kg)}} \times t_g^{(hours/day)} \times t_y^{(days/year)} \ (kg/year)$$

Table G.1 Calculated cost of fuel in domestic heating systems (continued)

- **Fuel Costs and Consumptions for Lignite Fired Stoves**

$$M_y = \frac{5{,}000}{\eta_{bl} \times 3{,}500} \times 10 \times 180 \times 1{,}900 = \frac{4.9 \times 10^6}{\eta_{bl}} \text{ (TL / year)}$$

$$T_y = \frac{2{,}571}{\eta_{bl}} \text{ (kg / year)}$$

- **Fuel Costs and Consumptions for LPG Fired Stoves**

$$M_y = \frac{5{,}000}{\eta_{bl} \times 11{,}200} \times 10 \times 180 \times 15{,}083 = \frac{12.1 \times 10^6}{\eta_{bl}} \text{ (TL / year)}$$

$$T_y = \frac{804}{\eta_{bl}} \text{ (kg / year)}$$

- **Fuel Costs and Consumptions for Natural Gas Fired Stoves**

$$M_y = \frac{5{,}000}{h_{bl} \times 8{,}250} \times 10 \times 180 \times 6{,}480 = \frac{7.1 \times 10^6}{h_{bl}} \text{ (TL / year)}$$

$$T_y = \frac{1{,}091}{\eta_{bl}} \text{ (kg / year)}$$

- **R E S U L T S**

Lignite Fired Stoves	M_y= 7×10^6 TL/year=225US$/year, T_y= 3.6 ton/year
LPG Fired Stoves	M_y=12.7×10^6 TL/year=410US$/year, T_y=850 kg/year
Natural Gas Fired Stoves	M_y=8.4×10^6 TL/year=270 US$/year, T_y= 1.3 ton/year

Table G.2 Calculated cost of fuel use in domestic heating by boilers and electricity

ASSUMPTIONS for BOILERS	
• Area heated	$A = 100m^2$
• Number of days used per year	$t_y = 180$ days
• Number of hours use per day	$t_g = 10$ hours
• Number of dwellings in a building	$N_d = 20$
• Thermal power of the boiler	
Characteristics of the Boilers[1]	$Q_b = 200{,}000$ kcal/hour
• Thermal efficiencies of different boilers	
• Imported Coal Fired Boilers	
• Natural Gas Fired Boilers	
• Lower heat value and cost of the imported	$\eta_{bl} = 62\%$
coal	$\eta_{bl} = 85\%$
• Lower heat value and cost of the Natural	$LHV_{ic} = 6{,}000$ kcal/kg
Gas	$m_{ic} = 0.173$ \$/kg (June 1992)
	$LHV_{ng} = 8{,}100$ kcal/Nm^3
	$m_{ng} = 0.285$ \$/Nm^3 (June 1992)

- Annual Cost of Fuel Consumption in the Boilers

$$M_y = \frac{Q_b^{(kcal/hour)}}{\eta_b \times LHV^{(kcal/kg)}} \times t_g^{(hours/day)} \times t_y^{(days/year)} \times m, \ (\$/\text{year})$$

- Annual Fuel Consumption in the Boilers

$$T_y = \frac{Q_b^{(kcal/hour)}}{h_b \times LHV^{(kcal/kg)}} \times t_g^{(hours/day)} \times t_y^{(days/year)} \ (kg/\text{year})$$

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[1] Characteristics of boilers are taken from Durmaz, (1992).

Table G.2 Calculated cost of fuel use in domestic heating by boilers and electricity (continued)

- **Amount and Cost of Fuel for Imported Lignite Fired Boilers**

  (for 100 m^2 area and 20 dwellings)

$$M_y = \frac{200{,}000}{0.62 \times 6{,}000} \times 10 \times 180 \times 0.173 = 16{,}742\ (\$ / year)$$

$$T_y = 96{,}775\ (kg / year)$$

- **Amount and Cost of Fuel for Natural Gas Fired Boilers**

  (for 100 m^2 area and 20 dwellings)

$$M_y = \frac{200{,}000}{0.85 \times 8{,}100} \times 10 \times 180 \times 0.285 = 14{,}902\ (\$ / year)$$

$$T_y = 52{,}288\ (Nm^3 / year)$$

- **Amount and Cost of Electricity use**

  (for 50 m^2 area)

$$T_y = 5{,}000 \times 10 \times 180 = 9{,}000{,}000\ (kcal / year) \quad (1\ kcal = 0.001163\ kWh)$$

$$T_y = 10{,}467\ (kWh / year)$$

Cost of the 1 kWh ≈ 7500 TL (based on June, 1996 prices)

$$M_y = 5{,}000 \times 10 \times 180 \times 7500 = 78{,}502{,}500\ (TL / year)$$

- **R E S U L T S** (based on 50m^2 area heated)

Imported Coal Fired Boilers	M_y = 418.55 US\$/year ,	T_y = 2,419 kg/yr
Natural Gas Fired Boilers	M_y = 372.55 US\$/year ,	T_y = 1,307 Nm^3/yr
Electricity	M_y = 945.81 US\$/year ,	T_y = 10,467 kWh/yr

Table G.3 Costs of alternatives of electricity use for domestic heating in Ankara

Heating Systems	Annual Energy Costs (10^6 TL)	Annual Investment Costs (10^6 TL)	Annual Total Costs (10^6 TL)
System based on limited heat storage	238,823	187,824	426,647
Heating by night-time price-list	113,648	295,800	409,448
Heating by average power	270,450	158,025	428,475
Heating by radiator	135,225	90,300	225,525

Source: Uluğ, 1987