Development of Energy and Emission Control Strategies for Iran

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Abbreviations and Acronyms

AFBC	Atmospheric Fluidized Bed Combustion
AQCC	Air Quality Control Company (Tehran)
bbl	Barrel (1 barrel (bbl) crude oil = 42 gallons = 5.8 million Btu = 6.119 GJ)
bbl/d	Barrels of oil per day
CCP	Combined Cycle Power plant
CEC	Commission of the European Communities
CHP	Combined Heat & Power production
CNG	Compressed Natural Gas
DIES	Diesel generator
EC	European Community
EFOM-ENV	Energy Flow and Optimization Model - Environment
EHC	Environmental High Council
ESCAP	Economic and Social commission for Asia and the Pacific
EPA	Environmental Projection Agency
EU	European Union
FFYDP	First Five Year Development Plan
FBC	Fluidized Bed Combustion
FGD	Flue Gas desulphurization
F.O.B.	Free On Board
GAMS	General Algebraic Modelling system
GDP	Gross Domestic Product
GEF	Global Environment Facility
GHG	Greenhouse Gases
Gt	Gigatonne = 10^{9} tonnes
GTU.	Gas turbine power plant
HYD.	Hydro power plant
IEA	International Energy Agency
IGCC	Integrated Gasification Combined Cycle

IIP	Institute for Industrial Production, University of Karlsruhe
IPCC	Intergovernmental Panel on Climate Change
IPR	Integrated Resource Planning
JICA	Japan's International Cooperation Agency
LCP	Least Cost Planning
LNG	Liquified Natural Gas
LPG	Liquified Petroleum Gas
Mt	Megatonne = 10^{6} tonnes
MWh	Mega-Watt hours (10 E+6 Watt-hours)
NUC.	Nuclear power plant
OECD	Organization for Economic Co-Operation and Development
OPEC	Organization of the Petroleum Exporting Countries
PBO	Plan and Budget Organization (Iran)
PFBC	Pressurized Fluidized-Bed Combustion
PJ	Peda Joul (10 E+15 Joule)
ppm	parts per million
PRI.	Primary measures for NO_x emission reduction
REN.	Renewable energy
Res./Com.	Residential/Commercial sector
SCR	Selective Catalytic Reduction
SFYDP	Second Five Year Development Plan
SNCR	Selective Non-Catalytic Reduction
STU.	Steam turbine power plant
TSP	Total Suspended Particulates
UNDP	United Nations Development Program
UNEP	United Nations Environment Program
UN-ECE	United Nations – Economic Commission for Europe
WB	World Bank
WHO	World Health Organization

INTRODUCTION

Energy consumption in Iran is increasing as a consequence of economic and social development on the one side and huge and low-priced accessible energy resource on the other side. The driving force behind the economic growth is the foreign currency obtained from the export of domestic energy resources especially crude oil. Therefore, the increasing of energy consumption causes that the export capacity of oil produced in Iran is being swallowed by the domestic demand and as a result income of foreign currency is going down. In spite of the large energy reserves of oil and gas, great changes in the political structure of Iran over the last 20 years and the war between Iran and Iraq which have brought a shortage of foreign currency, have been the obstacles for the expansion of energy extraction and production capacity [98].

The growth of energy consumption together with low quality fuel, inefficient methods of energy production and use, poor condition of vehicles and traffic congestion and lack of emission control technologies are confronting Iranian large cities with serious air pollution problems. Lack of urban planning controls has enabled industrial sources of air pollution to be built in close proximity to densely populated residential areas. Absence of monitoring equipment, assessment techniques and criteria, as well as legal frameworks for enforcement, have led to a situation where individuals face health risks from air pollution in the capital city of Iran (Tehran) and some other large cities. Especially, rising urban populations and the increased concentration of industry and automobile traffic in and around Tehran have resulted in severe air pollution, threatening human health and undermining the productivity of Tehran’s population. Considering the concentration of population in Tehran (12 million), a significant proportion lives in areas where air pollution exceeds the WHO[1] guidelines [230].

In order to support the future economic development in Iran, one of the most important objectives is the development of energy strategies, which ensure an efficient use of scarce economic resources. This objective can be pursued under a cost-efficient energy policy. Apart from this policy, to ensure that economic development takes place with minimum damage to the environment, but without limiting development opportunities, it is necessary to integrate environmental aspects into energy planning and policy making.

The general aim of environmental impact assessment is to create a basis to achieve a better environment, and more efficient utilization of resources, and sustainable development. Evaluations of environmental impact of action plans put forward by the Government should illuminate the effects on health and safety, soil, water, air, buildings and cultural heritage.

[1] World Health Organization

As there is a conflict between energy supply at minimum costs and expansion of emission reduction measures, cost-efficient emission control strategies are needed, which make it possible to reach a pre-defined emission reduction target at minimum additional energy supply costs. From a techno-economic point of view, such an emission control strategy consists of mixed technological measures, including emission reduction and energy conversion technologies, which are qualified to achieve this objective. An adequate energy environmental tool must be able to define the measures, which should be taken to control air pollution in an efficient way or the strategies which could be recommended for Iran to reduce air pollution in a cost-efficient way.

Considering that the total volume of pollutants emitted in the whole country is far lower than in the developed countries, the stringent standards cannot be applied with regard to the large deficit of financial resources. On the other side, achieving sustainable development requires limitations on the consumption of fossil fuels in various energy sectors and the appropriate energy and emission control strategies to prevent emissions of pollutants like NO_x, SO_2, and CO_2.

The question arises, to which degree the total emissions must be reduced through a suitable choice of strategy. An acceptable approach for Iran is to reduce emission in those cities, where air pollution exceeds WHO guidelines like Tehran, and to limit emissions to these standards. The impacts of the externalities regarding air pollution on the emissions reduction strategies for the capital city must be analyzed. Therefore the conflict between energy supply costs in Tehran and emission reduction measures must be considered with regard to the externalities.

Study Purpose and Approach

The purpose of this study is to develop and analyse cost-efficient energy supply strategies for the reduction of NO_x, SO_2 and CO_2 emissions in Iran, which can be used for making constructive energy and environmental decisions. Various methods are being developed for energy planning and the definition of emission control strategies. They vary from econometric models to techno-economic models that analyze energy consumption in detail. The energy supply optimization models like MARKAL ([3] [29][59]), MESSAGE [5]or EFOM ([77] [100][214]), which have been developed based on linear programming, have proven to be suitable. The linear optimization energy supply model EFOM was developed by the European Union and later extended to an energy-environment model by the IIP[2] in order to integrate emission control targets and the analysis of environmental impacts of energy policy decisions into energy planning. This model, called EFOM-ENV ([37][126]) has been applied

[2] Institute for Industrial Production, University of Karlsruhe

successfully in all EU[3] member countries for the development of harmonized emission control strategies and some other countries. This planning instrument is considered to be adaptable to the Iranian specific energy and environmental conditions.

This analysis applies the EFOM-ENV model as a tool, a multi-period linear programming model which represents the whole energy system of a country or region including all processes from the primary energy extraction to the useful energy in different end-use sectors along the energy conversion chain. An adjusted version of the EFOM-ENV model is able to represent properly the specific energy system of Iran. The objective of this study, is to answer the following major questions:

- Which are the environmental impacts and associated costs of an optimal energy supply structure required to meet the final energy demand in Iran between 1998-2020?
- Which energy conversion and emission reduction technologies should be applied to reach minimum costs in Iran?
- Which changes in the technological energy supply structure ensue applying a cost efficient strategy in Tehran and which additional energy supply costs will be involved?
- Which energy conversion and emission reduction technologies should be applied to reach minimum costs in Tehran?
- Which effects of applying the externalities in the model to the development of NO_x, SO_2 and CO_2 emissions and associated costs can be expected in Tehran?

To meet the above mentioned objectives, this study is divided into four parts. The first part looks at the entire economy from an energy and environmental perspective and discusses some of the significant factors and introduces some of the energy and environmental problems faced by Iranian society. The purpose of this analysis is to determine a future energy demand projection, to identify of the technological, economic and institutional structure of the energy sector in Iran, as well as future energy supply and emission control options, and finally to determine and estimate of emission data on a technological level. The results of this analysis will be used as a database including technological, economic and environmental data necessary for carrying out the analysis.

The second part introduces some of the analytical tools, which can be applied to energy and environmental decisions. Based on technical and economic analysis of the present structure and of the future options of the Iranian energy sector, an energy-environmental planning tool

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[3] European Union

has been developed and applied for this purpose. The necessary modifications of the methodological tool (the EFOM-ENV model) have been carried out and the measures for the reduction of NO_x, SO_2 and CO_2 identified, which are feasible under Iranian conditions.

In the third part, different scenarios have been defined to represent varying assumptions on basic parameters of the study (e.g. final energy demand forecasts or the future development of the world energy markets) and different emission control strategies.

Finally, the results of the EFOM-ENV model adapted to develop energy and emission control strategies for Iran are evaluated and different scenarios compared.

1 Energy Economy and Environment in Iran

The elaboration of emission control strategies requires an overall analysis of the energy and environmental situation of the country. This includes the energy consumption patterns, the technological basis of the energy sector, the fuel basis, the energy and environmental policies, as well as future energy supply and emission control options.

1.1 Situation of the Country and Economic Development

1.1.1 Geography Overview

Iran, a middle-eastern country, covers a total area of about 1,640,000 km^2 and is approximately four times larger than Germany. Iran is bordered by Azerbaijan, the Caspian sea and Turkmenistan to the north, Afghanistan and Pakistan to the east, the Gulf of Oman and the Persian Gulf to the south, and Iraq and Turkey to the west. In total Iran has a border of 8731 km of which 2700 km are water borders and 6031 km are land borders ([81][184]).

In general, the country is a plateau averaging 1,219 m in elevation. About 52% of the country consists of mountains and deserts and 16% of the country has an elevation of more than 2000 m above sea level. The main mountain chain is the Zagros Mountains, a series of parallel ridges interspersed with plains that bisect the country from northwest to southeast. Other mountain ranges run from the northwest to the east along the southern edge of the Caspian Sea. Along the eastern frontier of Iran several scattered mountain chains also exist. The Central or Interior Plateau is located in between these mountain chains and covers over 50% of the country. It is partly covered by a great salt swamp and partly by areas of loose sand or stones with stretches of better land near the foothills of the surrounding mountains. The eastern part of the plateau is covered by two salt deserts. Except for some scattered oases these deserts are uninhabited [81].

Among the rivers and streams, the only navigable river is the Karun. In this river, shallow-draft boats can negotiate from Khorramshahr to Ahvaz, a distance of about 180 km. Several other permanent rivers and streams also drain into the Persian Gulf, while a number of small rivers that originate in the northwestern Zagros or Alborz drain into the Caspian Sea. On the Central Plateau, numerous rivers form from snow melting in the mountains during the spring and flow through permanent channels. Most of them have dry beds for the greater part of the year. They drain eventually into salt lakes that also tend to dry up during the summer months.

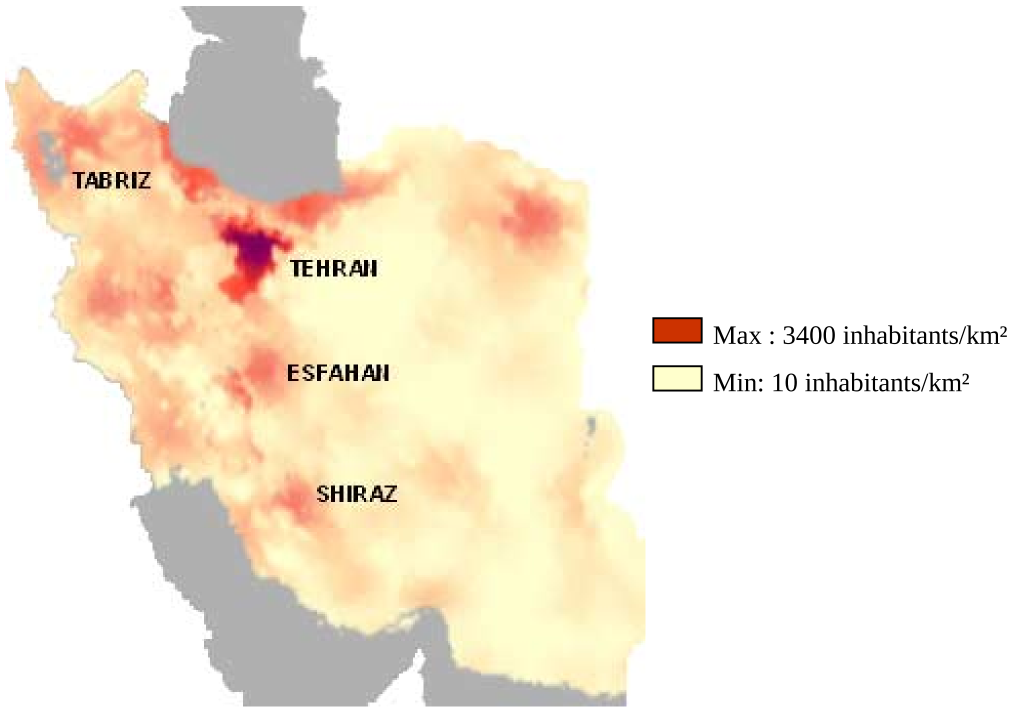
The climate of Iran is one of great extremes due to its geographic location and varied topography. The climate ranges from subtropical to sub polar. In the northwest, winters are cold with heavy snowfall and subzero temperatures during December and January. Spring and fall are relatively mild, while summers are dry and hot. In the south, winters are mild and the summers are very hot, with average daily temperatures in July exceeding 38° C. On the Khuzestan plain, the summer heat is accompanied by high humidity.

The annual rainfall ranges from less than 50 mm in the deserts to more than 1600 mm on the Caspian Plain. The average annual rainfall is 252 mm and approximately 90% of the country is arid or semi-arid. Overall, about two-thirds of the country receive less than 250 mm of rainfall per year.

1.1.2 Population

The latest census, which was taken in 1996 by the Statistical Center of Iran, put the total population at about 60 million people, of which about 61.7% lived within urban areas [184]. The average population density is about 36.7 inhabitants/km², but as Figure 1-1 shows the concentration of population is much higher in the northern and western parts of Iran. It ranges from less than 10 inhabitants/km² in the eastern part of the country up to more than 150 in the Caspian Plain in the north, which is by far the most densely populated region in the country.

Figure 1-1: Estimated Population Density in Iran [40]



As shown in the above Figure, in the Tehran province the population density is the highest and has 3400[4] inhabitants/km². Tehran city with more than 10 million covers $^1/_7$ of the total population of Iran. Mashhad in the northeast, Tabriz in the northwest, Shiraz and Isfahan in the center of Iran with about one million are the next largest cities.

After the Islamic revolution in 1979, due to the lack of birth control, population growth increased from 3.2% per year to 4% in the 1980s. The annual demographic growth rate was estimated at 3.4% over the period 1980-1990 and at 2.6% over the period 1990-1994. However, the population growth rate has declined from 3.2% to 1.8% in the end of 1990s.

The age distribution in Iran has the typical structure of many developing countries. 39.51% of the population is younger than 14, 56. 12% are between 14-64 and 4.32% older than 64 years old.

1.1.3 The Structure of the Iranian Economy

Iran's economy is a mixture of central planning, state ownership of oil and other large enterprises, village agriculture, and small scale private trading and service ventures. Oil occupies a central position in the Iranian economy [8]. The high income from the petroleum industry led to rapid growth of the entire economy in the 1960s and 1970s. The arrival of foreign capital and the establishment of new industries slowed noticeably due to the consequences of the Islamic revolution in the late 1970s [69]. The revolution resulted in the loss of 2 to 2.5 million barrels[5] of oil per day (bbl/d)[6] between November 1978 and June 1979. Economic activity was further damaged by the war with Iraq, which broke out in 1981 and lasted six and a half years. In 1980 Iraq’s crude oil production fell 2.7 million (bbl/d) and Iran’s production by 600,000 bbl/d during the Iran/Iraq war. The loss of oil resulted in a 150% increase in the price of a barrel of oil because of panic buying in the market. The combination of these two events resulted in an increase in the oil price from US$14 in 1978 to US$35 per barrel in 1981. The rapid increase in the oil price caused several reactions among customers including the development of more energy efficiency in industrial processes and energy conversation measures in the household and transport sectors. These factors along with global recession caused a reduction in the demand, which led to falling crude oil prices in 1981-1986 (see Figure 1-2). Therefore another event that also had a major negative impact on the country’s economy over the same period was the oil price depression, which resulted in a significant decline in the country’s revenue. The reduction of the oil prices and the strong dependence of income on oil exports forced the government to initiate restriction measures in

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[4] The latest census (1996) by the Statistical Center of Iran, put the total population in Tehran at 6,758,845 inhabitants. Total area of Tehran is about 2000 km².

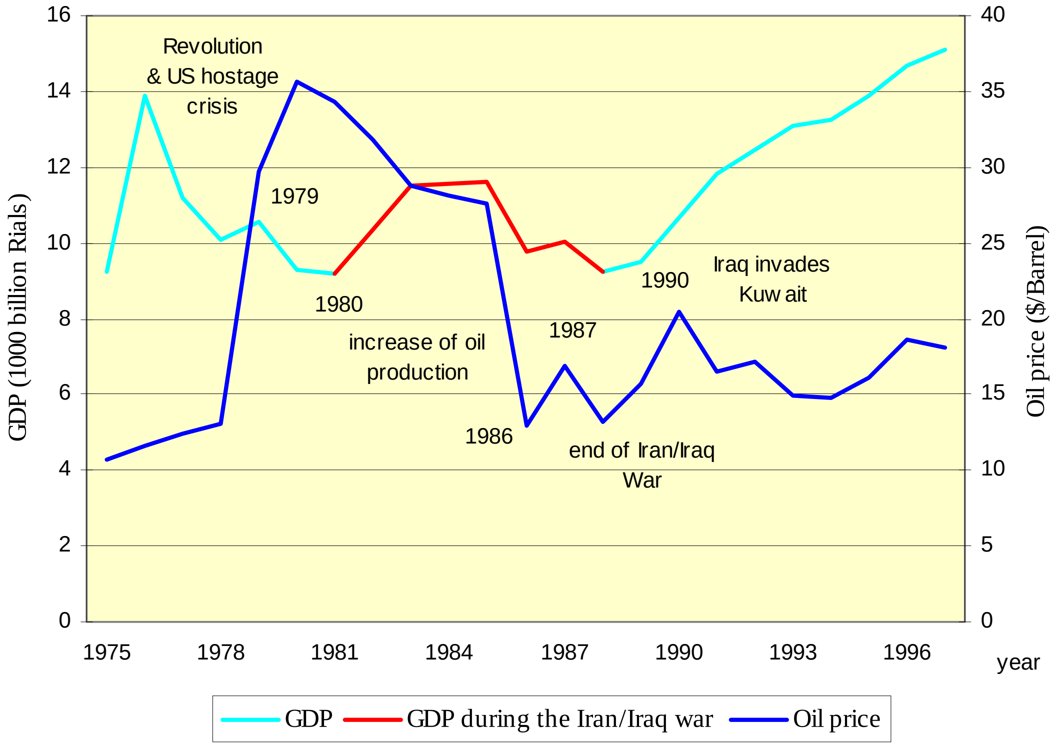
[5] barrel (bbl) crude oil = 42 gallons = 5.8 million Btu = 6.119 GJ

[6] barrels of oil per day

the early 1990s. Despite some improvement in the non-oil exports during the early 1990s the economy has remained dependent on the oil sector.

As the recipient of the oil revenues the state is the only dominant power in the domestic economy in consumption terms. Due to the dependence on oil income, Iran's economic policy has been based on three pillars: maximum subsidies, minimum taxes, and maximum state control. The role of the petroleum revenues in the economy helped the government to intervene and ignore market economy. On the other side the eight-year war with Iraq caused economic dislocation and disinvestments, which resulted in low rates of growth in the industry and the oil sector. Since 1989 the government has attempted with different degrees of success to liberalize the economy, to reduce government deficits, and encourage foreign trade and investment. The government planned to cut subsidies on basic goods in 1999, collected taxes from some foundations and started privatizing thousands of inefficient state-controlled enterprises [9].

Figure 1-2: Variation of the GDP in Iran and Oil Price from 1975-1996 [193] [238]



Iran is a lower middle-income country, with a GDP[7] of US$82 billion i.e. US$1300 per inhabitant. In 1976 real GDP reached a peak. After this, due to the political confusion resulting from revolution domestic investment and crude oil production slumped. There was a period of considerable minus growth up to 1981. Then, although the country was at war until the mid 1980s, crude oil production recovered and the economy turned round. However, in consequence of the great fall in crude oil prices in 1986, income from oil decreased again significantly and the economy also fell into minus growth. So that in 1986 GDP growth reached minus 6.5%. After a protracted period of economic stagnation in the 1980s, real GDP growth picked up in the early 1990s, with rates of over 11% in two successive years. Figure 1-2 shows that the GDP growth was at 4.2% in 1995 and 5.2% in 1996, the highest in five years. Subsequent oil price reductions slowed down GDP growth to 2.9% in 1997. In 1996 oil contributed directly to over 16% of Iran's GDP and accounted for about 80% of the total export revenues ([73][78][80]).

One of the main problems is the domination of oil, the source of more than 80% of the foreign currency income and around half of the total revenue, which has made the Iranian economy susceptible to fluctuations in the international oil market. However, a large obstacle to economic development is the political indecision, particularly regarding foreign policy ([38][90]). The economic sanctions by U.S. and western European countries and the blocking of Iran's foreign assets are also the main factors which have influenced the development of the Iranian economy since 1979 [217].

Table 1-1: Key Economic Indicators in 1999 [229]

Indicator	Amount
GDP—real growth rate	4.1%
GDP—per capita: purchasing power parity	US$6,050
GDP by agriculture	26%
GDP by industry	39%
GDP by service	35%
Inflation rate (consumer prices)	14.2%
Labor force	15.4 million
Labor force—by occupation	Agriculture 33%, Manufacturing 21%
Unemployment rate	Over 20%
Exports	US$32.2 billion (f.o.b.)
Imports	US$18.4 billion (f.o.b.)

[7] Gross Domestic Product

The import substitution strategy in the industry sector in the 1980s and the need of foreign currency for the industrial sector caused the economy to stagnate. The general nature of large enterprises as well as bureaucratic mismanagement and corruption has reduced their efficiency [4].

- ***Industry***

Industry in Iran can be classified into big industry and small-scale industry. The industrial plants which employ more than 10 workers, fall under the big industrial category. The latest statistics for 1993 show that the number of big industries has reached 6,098, petroleum, petrochemicals, textiles, cement and other construction materials, food processing (particularly sugar refining and vegetable oil production), metal fabrication being the largest branches. The large public enterprises account for approximately 70% of value added in manufacturing industries and have a relatively intensive production while the private sector has been characterized by more labor-intensive activities. 66.2% of the industrial enterprises are concentrated in large cities such Tehran, Isfahan, Mashahad, Tabriz and Arak.

The small-scale industries are scattered throughout the cities and the rural areas. It is estimated that there are 1.2 million small rural workshops of which 81% are textile production. Their share of the value-added to the entire economy is negligible. Textiles with 35%, food products with 30%, machinery, tools, and metal-works with 14% account for the total value-added of the small-scale industry.

Figure 1-3: The Development of GDP in the different Economic Sectors [46]

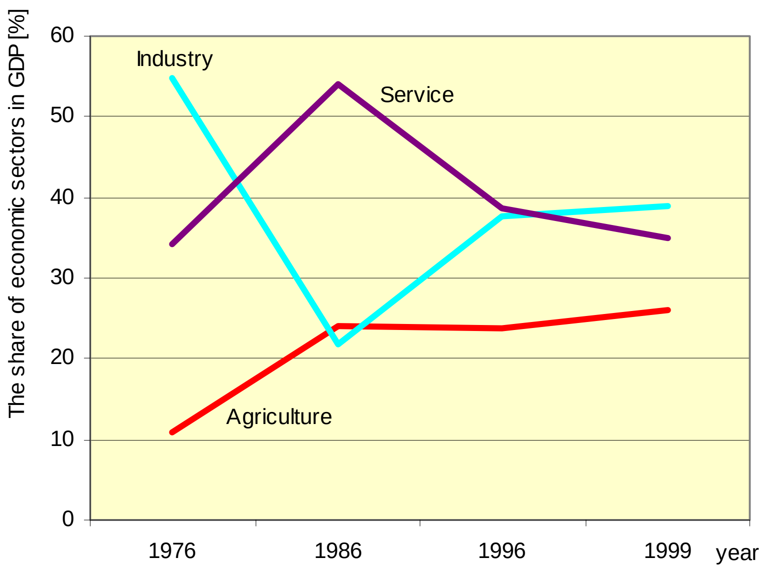


Figure 1-3 indicates the Development of GDP in the different economic sectors. The industrial sector remains increasingly dependent on imported raw materials and parts for its growth. This fact led to a considerable decline between 1979-1989 due to the foreign currency crisis arising from the oil price reduction. Afterwards with the end of the Iran/Iraq war and the growth of the oil price, the share of industry in the economy increased to 37% of GDP in 1996. Apart from the oil sector, the economy in 1995-96 had a growth of 19.5% in the food industries, 17.1% in paper production, 22.5% in chemical products and 11.4% in non-metallic mineral products ([46][[81]).

- ***Transportation***

Iran has a total of about 162,000 km highways of which about 81,000 km are paved (including 470 km expressways) and 81,000 km are unpaved. 3706 km of the main roads are also under construction. The railways total 7,286 km including 94 km broad gauge (1.676 m) and 7,192 km standard gauge (1.435 m) of which 146 km are electrified. The waterway total 904 km, of which the Karun is the only navigable river with about 130 km.

The transportation of goods within the country still relies to a high extent on trucks. Because of the geographical situation of the country, the most important points for the entry and exit of goods are along the country's water border. About 94% of the total commodities enter the country via ports and 6% arrive in the country by land via the border crossing. The surface transport fleet for the displacement of goods and passengers comprises 170,149 trucks and 577 busses. The capacity of the fleet is 542.6 Mt[8] of goods and 350 million passengers. 81% of imported goods come by trucks and the remaining 19% by train. The total quantity of goods transported by road, sea, and air in 1999, reached 60 Gt/km[9] and the share by rail reached 13.5 Gt/km. 9.7 % of passengers were transferred by railway, of which 40% to 50% traveled on the Tehran-Mashhad route [81].

The Iranian marine fleet has a total of 132 ships including 47 bulks, 47 cargos, 26 tankers, 5 containers and 6 large-load carriers. Iranian shipping lines carried 11.5 Mt/rent of goods in 1999, i.e. 10.4 Mt/rent by Iranian ships and 1.1 Mt/rent by chartered ships. Two ports on the Persian Gulf with 11.5 Mt have the largest share in handling imported goods [175].

There are fifty airports, of which six airports operate internationally and six airfields belong to the Ministry of Oil. The Iranian air fleets carry about 5 million passengers and 25,141 t of cargo in internal and international flights per year.

[8] Mt = Megatonne = 10^{6} tonnes
[9] Gt = Gigatonne = 10^{9} tonnes

- ***Agriculture and Forestry***

Because of the poor soil and the lack of sufficient water distribution in many areas, cultivated agricultural lands occupy only 11% of the whole area (16.5 million ha.). The western and northwestern sections of the country are the most fertile. Less than one-third of the cultivated area is irrigated and the rest is devoted to dry farming.

Agriculture plays an important role in the economy of Iran with a great potential for development. From 1989 to 1994, agriculture accounted for an average 27.8% of GDP, and employed 33% of the labor force in 1999. The share of agricultural activities was US$25 billion in 1997 and produce accounted for about 47% of the non-oil exports [60]. Small farms are predominant in the agricultural sector. Due to the size of individual operations, tradition, high cost of machinery and the low labor costs, mechanization is limited to sizable farms. Agricultural programs for modernization, mechanization, and crop and livestock improvement have been undertaken to increase agricultural production [70].

Iran’s forests cover approximately the same amount of land as its agricultural crops. The largest and most valuable forested areas are in the Caspian region, where many of the forests are commercially exploitable and include both hard and soft wood.

1.1.4 Economy Policy Framework

The economic policy of contemporary Iran has been formed under the complicated influence of a number of internal and external factors. Naturally, the modifications resulting from the Islamic Revolution have affected not only politics and society but also the country's economy. Regarding Iran's economic development two important phases can be differentiated.

- ***Iran's Economy Between 1979 and 1988***

The war with Iraq (1980-88) caused economic dislocation, and disinvestments resulted in low rates of growth in both industry and the oil sector [69]. During the first phase directly following the Islamic Revolution the ruling institutions took drastic measures to increase state control over the economy. The enforcement of this policy influenced those major industries which already had been under the supervision of state authorities such as oil, gas, steel producing companies, petrochemical plants and public utilities (water and electricity). The government also extended its control to other industries which it deemed of vital importance to the country's economy, e.g. the metal processing industries, the car industry, as well as shipyards and aircraft construction enterprises [113].

- ***After the War (1989-1999)***

After the nationalization policy during the pre-war period, Iran embarked on a program for infrastructure reconstruction and the economic reform constitutions [129]. The First Five-Year Development Plan (FFYDP), covering the period 1989/90-1993/94[1] aimed at an annual average GDP growth of 8% ([2][21]). The Policies undertaken in the FFYDP included decontrolling most domestic prices, raising public utility rates, removing many non-tariff trade barriers, lowering income tax rates, eliminating the bank credit ceiling, starting to privatize public enterprises, and liberalizing the exchange system.

Following the long war with Iraq, the economy turned around to grow at a strong rate averaging 8.1% per year during 1989-92. The industrial sector had the highest growth (11.5% per year on average) and the agricultural sector had the weakest (5.7% per year). The production volumes of natural gas and large industries were more than 40% in 1992, above their respective levels in 1989. With a steady increase in the non-oil exports, the volume of exported goods reached from around US$l billion in 1989 to US$3 billion in 1992.

The FFYDP considered foreign investments up to the value of US$17 billion, the creation of four free trade zones, the abolishment of a number of import bans, and the support of non-oil exports.

The realistic policy, which was assumed, in order to privatize the economy was instrumental for economic growth and prosperity. The GDP increased during a period of 4 years from 10,664.9 billion Rials to 13,464 billion Rials. The value added in the industrial sector during the FFYED Plan was 9.2% at constant prices and the share of income from this sector in the GDP rose from 10.5% to 16.5% at the end of the plan. The average growth rate in the agricultural sector was 6.3% during the first four years.

The earlier economic and policy reforms were pursued under the country’s Second Five Year Development Plan (1994/95-1998/99 SFFDY) [165]. The aims of this plan were to obtain a 6% real growth rate with an individual digit inflation performance of one, to reduce the reliance on oil revenues and to unify the exchange rate system, a progressive liberalization of the economy with increased participation of the private sector. At least 2400 state-owned companies, including 30 in the petroleum, petrochemical, steel, and electricity sectors, are to be privatized. The second five-year plan gave attention to foreign investments, foreign credits, and import goods not deemed vital for the country's economy.

The plan’s targets included phasing out subsidies on fuels, electricity, and air transport. During the second five-year plan, subsidies on petroleum were to be substantially reduced

[1] Fiscal year ending March 20

from US$10 billion at the end of the first five-year plan to US$5 billion at the end of the second plan. It encouraged a shift from oil to natural gas for industrial and household consumption, and emphasized free market reforms.

Iran experienced continued macro-economic difficulties in 1995, as the country tried with a government program to cope with the excesses of the reconstruction boom of the early 1990s, the government's failure to implement promised economic reform measures, and a stagnant petroleum sector. In general, Iranian government policies failed to respond adequately to the array of economic problems besetting the country. The measures were insufficient and could not resolve Iran's debt problems. Despite broad rescheduling of arrears in 1994, there was a recurrence of commercial arrears during 1995.

The Third Five-Year Economic Development Plan, covering the period 1999/00 - 2000/04 plans greater transparency in the macroeconomic system and regulatory frameworks, budget reforms, tax reforms, downsizing of the government’s role in economic activities and privatization of government enterprises, promotion of the private sector, dismantling of monopolies and promoting of competition [95].

1.1.5 The Exchange Rate System

Since the 1970s the exchange system and exchange rate arrangement in Iran have been characterized by multiple exchange rates and the associated exchange regulations and import controls. The complexity and extent of restrictiveness of the regime have varied considerably in response to the major external and domestic shocks, and the foreign exchange availability ([28][51][88][130]).

The exchange rate system was significantly liberalized and simplified on January 21, 1991 when the number of exchange rates in the official market was reduced from seven to three ([20] [52]). From this date to March 21, 1993, there were three official rates used within the banking system and one free market rate outside the banking system. Since 1995 the exchange system remained virtually unchanged for almost three years in a constant appreciation of the real effective terms of each of the two official rates and in a continued depreciation of the parallel exchange rate. In July 1997, the authorities responded by permitting exporters to sell ‘import certificates’ through the stock change at a substantially more depreciated exchange rate. These import entitlements combined with the export exchange rate implied a market exchange rate. The basic official exchange rate, pegged to the U.S. dollar at Rials 1750 per U.S. dollar, is applied to the oil export receipts, import of the essential goods, imports for priority projects, and imports and service payments for essential services, and debt service on priority projects. The official exchange rate for export, pegged to the U.S. dollar at Rials 3000 per U.S. dollar, was applied to all other transactions including non-oil exports, imports and services not covered by the official rate. The unification of the exchange rate was among the key objectives of the Second Five-Year development Plan.

The free non-market rate is determined by foreign exchange brokers and moneychangers in a market where foreign exchange is bought and sold freely. The main source of foreign currency in this not legally regulated market is the non-oil exports, which meet the demand for foreign exchange related to most nonessential goods and services that are not eligible for the official rate.

1.1.6 Iran's Foreign Economic Relations

In the years before the 1970s, foreign companies did not contribute much to the Iranian industries. This contribution did not exceed 8% in the years up to 1977. The Major foreign companies practically began their activities in Iran after the establishment of the Center for Attraction and Protection of Foreign Capital in 1957 and the resumption of oil exports following the post-World War II economic recession. Until 1974, a total of 162 major multinational and foreign companies were active in Iran. They mostly came from America, Japan, West Germany, England and France. Since foreign private capital constituted less than 10% of the total investments in the industrial sector, the effects of this capital in terms of providing financial and foreign currency sources on the macro variables of the Iranian economy was not so important. The direct effects of these activities could include the creation of the industrial jobs, transfer of technology and technical know-how and training of man-power. The indirect effects take shape in the relations between input and output in the economy. Such effects create a chain of economic interactions, which eventually fill the missing links in the various industrial activities and play a key role in the fundamental economic changes and economic development of the society [94].

Following the revolution in 1979 the U.S. Embassy in Tehran was invaded and the staff members were taken as hostages. As a reaction against the hostage crisis, America blocked Iranian assets in the U.S. banks to achieve the release of the hostages, it placed an embargo on importing Iranian oil into the United States and severed diplomatic ties with Tehran and adopted a policy of "dual containment" of Iran and neighboring Iraq [34]. It touched off the second oil crisis in the United States.

In 1987, the Government of the United States prohibited the import of crude oil from Iran and in April 1995 imposed wide-scale trade and investment sanctions against Iran when it was accused of promoting international terrorism and developing weapons for mass destruction. Under the sanctions law, all American firms were prohibited from buying crude oil from Iran for sale to the Latin American and Far East countries. In December 1995, the U.S. Congress approved secondary sanctions against foreign companies investing more than 40 million dollars in the oil and gas industries of Iran [115].

The impact of sanctions has been magnified by Iran's inappropriate economic policies. Because of poor management, Iran ran into a foreign debt crisis in 1993/94, just as the United States began to apply economic pressure against the country. In 1993/94 Iran stopped borrowing from abroad and instead devoted between US$3 billion and US$4 billion a year to paying off its debt, besides paying interest. The change from a net borrower to a net repayer was a US$9 billion a year swing, and that meant imports had to be cut from US$23 billion in 1992/93 to US$13 billion a year in 1994/95 and 1996/97. By 1997, Iran had largely resolved its foreign debt problem and looked ready to resume more normal economic growth. That would have made Iran less concerned about the U.S. economic sanctions. But then oil prices dropped and fluctuation made Iran particularly vulnerable to continued U.S. economic pressure.

With a population which has doubled in less than 20 years, oil price reductions to one third of the pre-1979 period, widespread war damage and a capital-intensive economy, especially in the oil, gas and petrochemical industries, Iran is faced with a shortage of hard currency. For example Iran will require over US$30 billion in investments only for its oil sector by the year 2025. Besides the U.S. sanctions, the political and economic risks of dealing with Iran have limited foreign involvement. Too much intervention, sudden changes of policy and mismanagement have created a feeling of insecurity both inside and outside the country. Foreign investors allow their capital to become vulnerable, while even Iranian nationals hesitate to invest in the long-term national projects. However the government implemented a major change in policy in 1995 when Iran invited foreign participation in the development of its petroleum sector. The U.S. trade sanction laws have not only kept American firms out of Iran and reduced competition for investment in its petroleum sector but also they have denied Iran access to certain advanced technology. Apart from the US$2 billion investments by Franco-Malaysian-Russian companies no major investment has been made in Iran. The country's share of global investment is still small.

In July 1996, the European Union (EU) governments raised the issue of the extraterritoriality of U.S. laws over international trade matters, when the U.S. authorities moved closer to punishing foreign firms doing business with Iran. The U.S. then proposed to impose sanctions on the European companies making investments in Iran [54]. Obviously, the sanctions against Iran remain operative, but in practice the European companies are doing substantial business with Iran either directly or through intermediaries. The EU has strengthened its already good export controls on dealing with Iran. Since Europe was the main beneficiary of the American economic embargo, it is not easy for European countries as a whole or even for a single country to give up Iran's market of 60 million people. The west European countries, the consumer of Iranian petroleum, import more than US$1 billion of oil. Iran's oil exports to the EU constitute about two-thirds of its overall exports, which exceeds about 15% of Europe's oil imports [94]. Approximately 70% of Iran's imports originate from the European Union countries. Some EU countries have gone as far as warning the U.S. that future development of its trade relations will be on condition that a satisfactory resolution of the dispute over U.S. legislation aimed at curbing trade and investment in Iran is found. Also, the French company Total has invested more than US$420 million in the Iranian Siri oil field after the American company Conoco withdrew following its country's economic embargo. Germany is the leading trade partner of Iran, followed by Italy and France.

Following the sanction and economic break off with the western countries, Iran has tried to intensify its economic relations with the neighboring states in the Persian Gulf and the members of the ECO[10]. Furthermore, in recent years, there has been a steady expansion of trade relations between Iran and the Former Soviet Union [103]. The relations with Iran's neighbors on the Persian Gulf will also continue to play an important role in the country's economic developments. Trade relations with countries in the Far East will further gain importance. This trend is already visible in Iranian trade relations with South Korea and Thailand. These relations thus reduce the share of OECD[11] states in the Iranian economy [72]. The observable extension of bilateral trade relations with these countries is based primarily on a mutual interest in the strategic investments in the non-oil industries.

1.2 Analysis of Energy Structure in Iran

Iran is one of the world's largest fossil fuel rich countries and holds 9% of the world's oil reserves and 15% of its gas reserves. At the end of January 1999, Iran reserved 93 billion barrel and 23 trillion m^3 of natural gas, i.e. the 4th and 2nd highest amount in the world [44]. The majority of these reserves is to be found near the Persian Gulf (see Figure 1-4). Of the forty producing oil fields, five account for two thirds of current production (Agha Jari, Ahwas, Bibi Hakimeh, Gachsaran, Marun) [141].

The majority of gas reserves are non-associated, with the largest field being South Pars, which has an estimated quantity of over 3 trillion m^3 of reserves. Newly discovered areas have more than doubled Iran's current natural gas reserves.

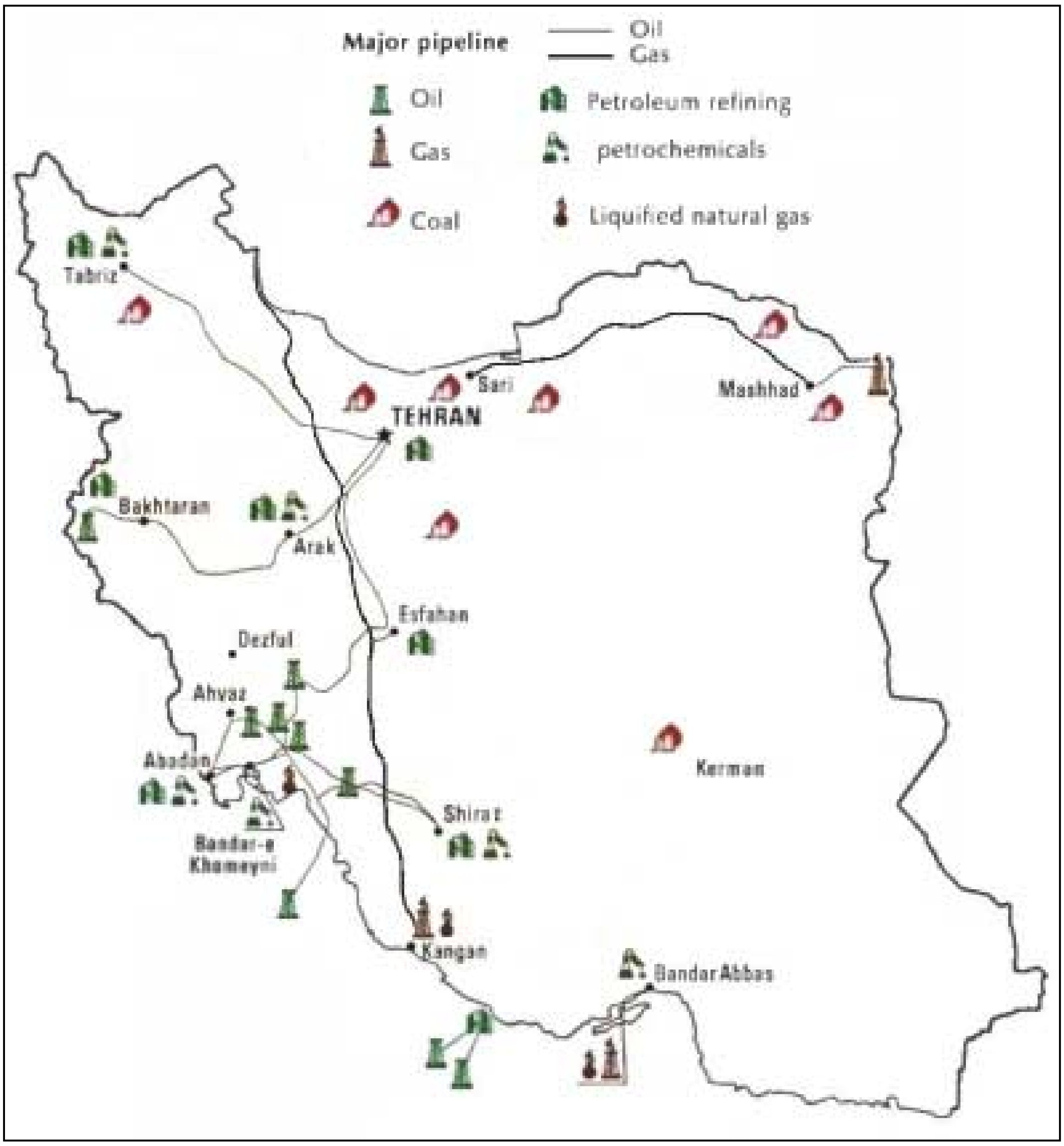
Due to the dependence of Iran's economy on oil and gas, and the need for investment both to increase production from existing fields and to discover new ones, the government's effort in recent years was based on attracting foreign investment in the Iranian oil and gas industries.

[10] Economic Cooperation Organization (Iran together with Pakistan and Turkey, are the founding members of the ECO, has accepted six other nations of Central Asia and Afghanistan as members).

[11] Organization for Economic Co-Operation and Development

Those are generally buy-back investments, based on which, the foreign investor receives its revenues from the direct sale of oil products. The energy projects will increase in the near and medium term future, as foreign investment is secured. Large reserves of both oil and gas ensure that this large market represents a long-term business opportunity.

Figure 1-4: Fossil Energy Resources in Iran



1.2.1 Domestic Primary Energy Resources and Supply

- ***Oil Resource and Production***

The 93 billion barrels of proven oil reserves are spread over 24 oilfields. The vast majority of Iran's crude oil reserves are located in huge onshore fields in the south west (Khuzestan region) near the Persian Gulf and the border with Iraq. Most of this crude oil is low in sulphur, with gravities ranging from 30-39^{o} API[12]. From a total of 73 billion barrels oil reserve, 62 billion barrels i.e. 84% are located in onshore fields ([192][193]). Iran's onshore field development work is concentrated mainly on sustaining output levels from the large, aging fields. Consequently, enhanced oil recovery programs are underway at a number of fields. In addition, Iran also is developing new reservoirs at fields such as Bibi Hakimeh, where deep formations at a depth of 4000 m have been proven to contain light crude oil. The most important of onshore oilfields and their reserves are: Agha Jari with capacity reserves of 14 billion barrels, Gachsaran with 16 billion barrels, Marun with 16 billion barrels and Bibi Hakimeh with 4 billion barrels.

Iran produces about 550,000 barrels of crude oil from eight offshore fields and plans to increase them to twenty. These fields which are mainly placed in the south west of Iran include: Doroud with a production capacity of 105,000 bbl/d, Salman with 105,000 bbl/d, Abuzar with 125,000 bbl/d, Forozan with 50,000 bbl/d and Siri C&D with 30,000 bbl/d.

Iran also has some oil and gas reserves in the Caspian Sea and has claimed 20% of this sea. The first step for discovery has been done and two exploration contracts have been awarded by Iran. It is estimated that the Caspian Sea's proven and possible oil reserves reach as high as 191 billion barrels, with huge natural gas reserves as well. Since the break-up of the former Soviet Union, territorial issues have arisen regarding rights to the Caspian Sea's resources. The treaties signed in 1921 and 1940 are still valid for Iran, implying that all countries bordering the Caspian must approve any offshore oil developments. Offshore exploration in the Caspian Sea has so far led only to marginal gas discoveries. Iran plans to build 400 km of pipeline from the Caspian Sea port of Neka to its refinery near Tehran with a capacity of

[12] API Gravity is a measurement of the gravity (weight per unit volume) of crude oil and other liquid hydrocarbons by a system recommended by the American Petroleum Institute (API). The measuring scale is calibrated in terms of "API degrees." The lower the API gravity, the heavier the oil. The higher the API gravity, the lighter the oil.

API Gravity = (141.5/Specific Gravity at 60*F) - 131.5

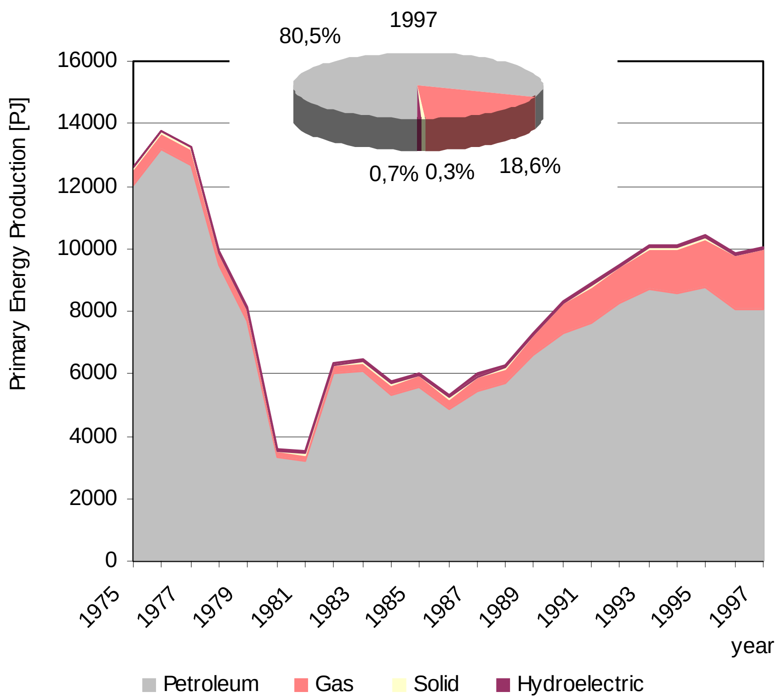
The fundamental SI unit for density is kg/m^3. Use of this unit is encouraged. However, units like g/cm^3 and kg/L are permissible. The traditional term “specific gravity” will not be used under the SI system. It will be replaced by the term “relative density.” API gravity disappears as a measure of relative density.

Heavy Oil has a low gravity of less than 28 API degrees or a high specific density of more than 0.887 g/ml.

Iranian heavy Oil has a gravity of 31-32 API degrees and 1.8 mass % sulphur, Iranian light Oil has a gravity of 33.5-34 API degrees and 1.4 mass % sulphur.

350,000 bbl/d and a pipeline that is capable of carrying 800,000 bbl/d of crude oil produced by Azerbaijan and Turkmenistan.

Figure 1-5: The Conversion and Production of Primary Energy in Iran [193]

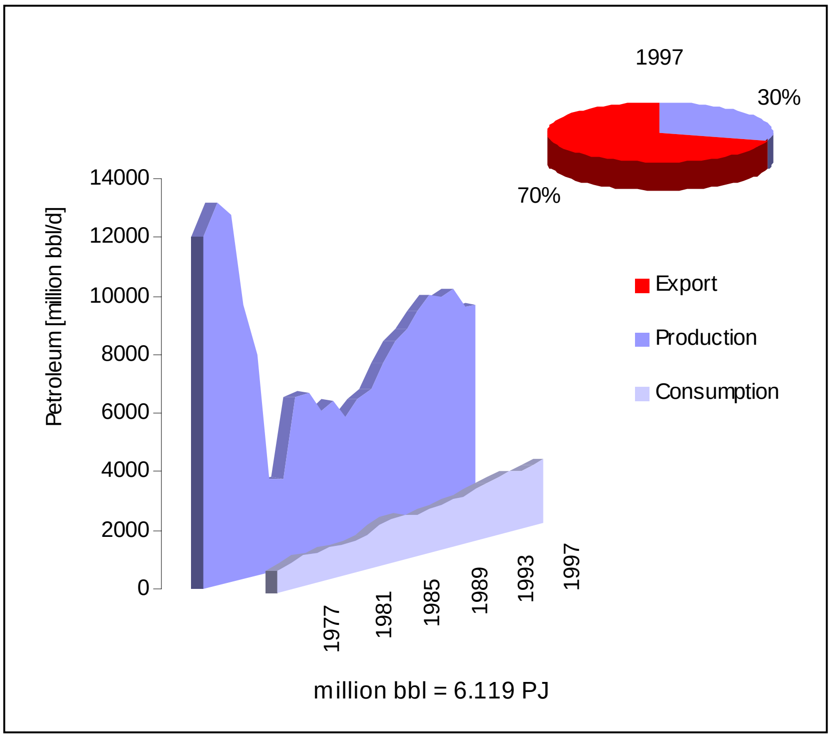


The Iranian oil industry has had many fluctuations since the revolution in 1997 and has faced numerous problems resulting from the economic sanctions and the Iraq-Iran war. In a period of four years (1970-74), oil production increased from 3.8 million bbl/d to 6 million bbl/d, the highest amount during the 1970s. Then it decreased from 1977-78 due to the strike of oil industry workers. Through the initial years after the revolution, Iran's oil industry was faced with the dismissal of foreign and Iranian experts and the fluctuations resulting from the recession caused by the former strike. The exports of oil products, which constituted a considerable figure before the Iran-Iraq war, stopped when Abadan Refinery was heavily damaged early in the war (The Abadan Refinery was repaired by the middle of 1992). Confronted with the Iraq-Iran war, in the period of 1980-1988 this industry sustained a large loss. It is estimated that the total damage to the installations reached 1511 billion Rials and US$92 billion by the end of the war. Oil production averaged about 2 million bbl/d during the eight years war and increased consistently to about 4 million bbl/d after 1988. With an increase in domestic consumption of oil and the reduction for oil production for the above mentioned reasons, the share of oil exports has sunk during the last 20 years. As Figure 1-6 shows, from the total oil production in 1997, 77% was exported and 23% was consumed in

Iran, whereas in 1975 the share of oil exports stood at 94% [192]. This also meant a sharp reduction in Iran's revenue. The main consumers of Iran's crude oil were the European countries, Japan, and other Asian countries in the post-revolution years.

In 1998, Iran came next to Saudi Arabia in oil production on a regional level, with an average crude oil production of 3.6 million bbl/d. These two countries produce more than half of the total regional production. Iran's OPEC quota is 3.6 million bbl/d but it produces about 10% above its OPEC quota and its current maximum sustainable capacity is around 4 million bbl/d. Iran plans to increase the production capacity to 800,000 – 900,000 bbl/d by the end of the third five-year development plan (March 2005). For this purpose it must boost oil production capacity 200,000 - 250,000 bbl/d each year, possibly surpassing 6 million bbl/d by 2010.

Figure 1-6: The Production and Consumption of Petroleum in Iran [193]



Despite the existing facilities, the country's crude oil production has decreased both at the onshore and offshore oil fields and has adversely affected its crude exports. This is due to the natural drop in the productivity of major onshore fields, a delay in the implementation of oil projects and in the necessary gas re-injection projects, as well as insufficient investments in oil infrastructure projects and a shortage of experienced personnel. Substantial investment will be required over the next 10 years to maintain production at current levels, or increase it as domestic consumption continues to increase.

The gas injection projects are expected to increase the onshore oil production capacity by at least 300,000 bbl/d. Most of this increased capacity will come from the 570,000 bbl/d Marun field, the 130,000 bbl/d Karanj field, and the presently inactive Parsi field. These fields have been susceptible to water encroachment and pressure problems have restricted oil production. At the Karanj field, gas injection facilities were installed in 1995, but with a second phase of gas injection at this field, it is expected to boost recovered oil reserves by 1 billion barrels.

The Azadegan field, Iran's largest oil discovery in 30 years, is estimated to hold 26 billion barrels of crude oil with the value of US$100 billion. The Soroush field is located about 50 miles west of the island Kharg and contains estimated recoverable reserves of 400 million barrels. The field contains three reservoirs, two of which hold heavy oil 19^{o} API[13] oil. It was severely damaged early in the Iran-Iraq war, and its 25,000 bbl/d production capacity has been closed down since 1979.

- ***Natural Gas***

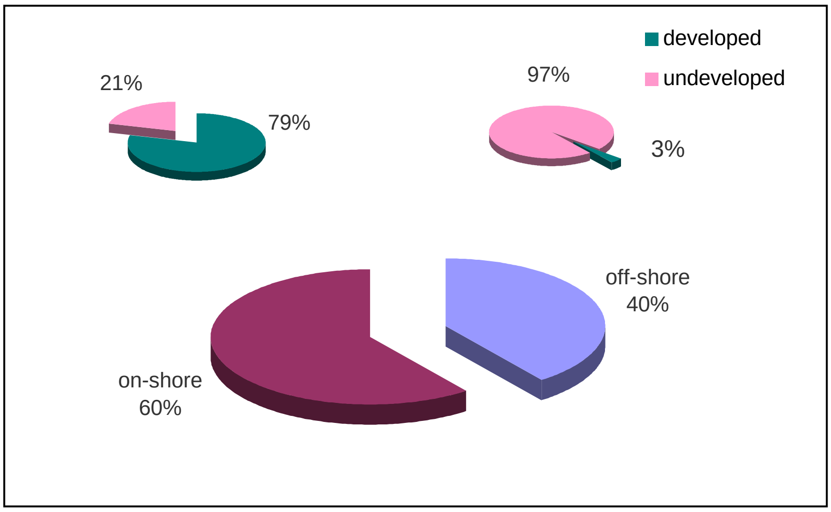
Before the oil is moved by pipeline to the refinery or tanker terminal, a so called “associated” gas under very high pressure must first be removed. For many years all of the associated gas was flared off near the wellheads, because of the problems and the expense of transporting it to the distant markets or utilizing it in Iran. Only a tiny fraction was used, mainly for power generation nearby. Besides the associated gas in the oilfield, which exists not only as a solution in oil-bearing strata but also as a gas-cap on top of the reserves, Iran has a number of independent gas fields. The bulk of Iranian gas reserves is located in non-associated fields. About 63% of the natural gas accounts for the non-associated fields and 37% of them are associated gas.

As Figure 1-7 shows, about 60% of the gas reserves are located at the onshore fields with approximately 7 trillion m^3 of associated gas, which is either dissolved in the crude oil or is in the gas caps. The main onshore fields are sited, one at the Nar field with a capacity of about 36 million m^3/day and the second at the Kangan field with a capacity of about 80 million m^3/d. The natural gas from these fields is used to be injected into the oil fields and to be supplied to the 2,000 MW power plant at the Bandar Abbas port. Between 5.5 million m^3 to 8.5 million m^3 of gas in excess of domestic consumption can be exported.

[13] See page 15, footnote 12.

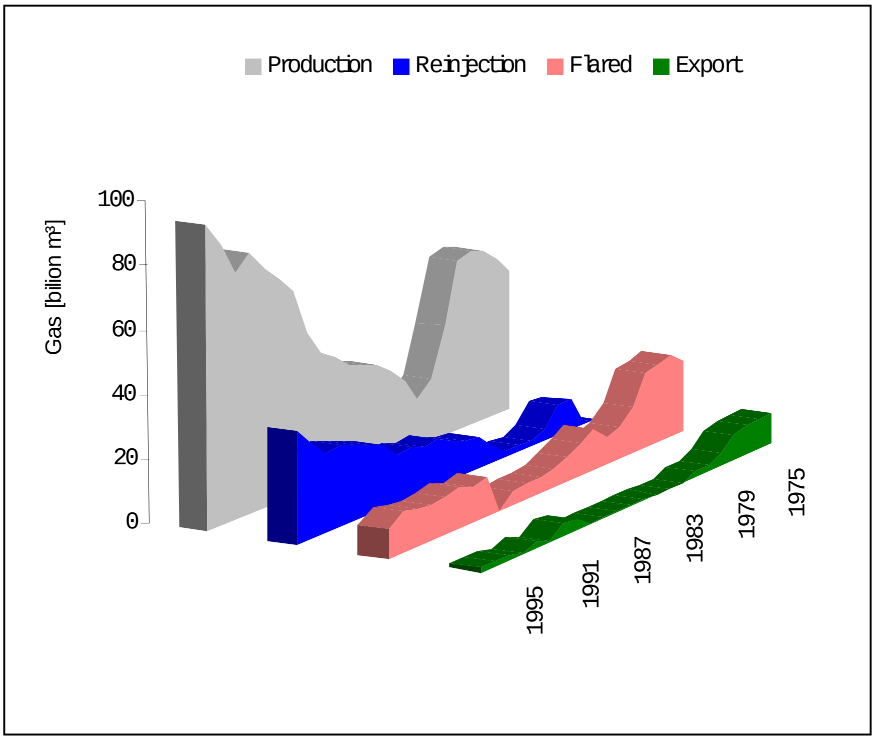
There are also two major off shore non-associated gas fields in the Persian Gulf which being developed, the South Pars and the North Pars field. This huge gas field which has been linked with the north field reserves, has a production capacity of up to 35 million m³/d. The natural gas from these fields is used in the domestic markets, to be re-injected into the onshore Gachsaran, Bibi Hakimeh, Binak and Agha Jari oil fields as well as for the export of 50,000 bbl/d of liquefied gas. The major part of the natural gas to be produced through the off shore development plans will be consumed domestically, re-injected into the old oil wells and exported.

Figure 1-7: The Status of Gas Reserves in Iran [193]



Besides the common usage, natural gas should be used for re-injection into the oil fields. Gas re-injection into the oil fields has been taken seriously in Iran and it began in the 1970s. As Figure 1-8 shows, the gas re-injection was continued, although with some delays in the 1980s and particularly since the end of Iran/Iraq war in 1988. After the war, gas production, re-injection and the reduction in flaring increased strongly. In 1997, Iran produced about 95 billion m³ of natural gas, of which 35 billion m³ were re-injected, 9 billion m³ were flared and, one billion m³ was exported. In 1990, Iran undertook an ongoing gas utilization program that is designed to boost production to about 140 billion m³ per year by 2010, reduce flaring, provide gas for re-injection programs, and allow for increased gas exports abroad.

Figure 1-8: The Gas Production Situation [193]



The gas injection programs for 31 billion barrels, leading to an increase in the recoverable reserves of about 5 billion barrels, could require 4.2 million m³ of gas during the field's remaining life. Gas-related programs at the Agha Jari field, as well as at the Binak, Kupal, and Ramshahr fields, are dependent upon the development of Iran's non-associated gas reserves at the South Pars and North Pars fields in the Persian Gulf.

Considering that Iran’s share in world gas production is only 3% compared with Russia’s production which is as high as 27%, such huge reserves show the significant role of Iran’s gas production in the future of the world gas market. Iran's aim of finding its place in the future world gas markets is made difficult by the existing inadequate structures [65]. The gas trade has a different nature to the oil business. While oil production could be completely separated from the processing and marketing, the gas trade operates in a chain-like manner from the production to the final consumer. Lack of adequate export infrastructure is the most difficult problem. The routing options for new pipelines are fraught with legal or political difficulties. Many proposed pipelines must pass through or near politically troubled areas. On the other hand, the export of gas by Iran can be been limited due to the increase of local demand and the need for the re-injection of gas into the oil wells.

Although domestic gas consumption is growing rapidly, Iran continues to promote export markets for its natural gas. In 1997, the export of natural gas amounted to about 10 billion m³.

The Iranian oil ministry plans to complete three gas export pipelines to Turkey, Armenia, and Nakhichevan and has already signed agreements for the sale of natural gas with some of the newly independent republics of the former Soviet Union including Georgia, Ukraine and Azerbaijan, in addition to reaching an agreement in principle with officials of the republic of Armenia. Under the gas plans, Iran aims to export 12.7 Million m^3 per day of gas by 2000, rising to 113 Million m^3 per day by 2005. By 2005, two further pipelines are planned to Europe and India, in addition to an LNG[14] facility for the export to Asia ([192][193]).

Table 1-2: The Future Plans of Gas Exports [44]

Name of contract	Begin of supply	Duration (year)	Amount of contract (US$)	Amount of supply (Mm^3/d)[15]
Iran-Turkey (1996)	1999	22	20 billion	28.2
Iran- Armenia (1995)	1999	15	135 million	2.8
Iran- Pakistan/India (1995)	End of 1999	-	3 billion	45

Heavy costs of pipeline construction and the lack of foreign currency have delayed the implementation of gas projects. Despite these problems, Iran has made some progress regarding the export of natural gas to Turkey and Pakistan by pipeline. In February 1996, Tehran and Ankara signed a 20 billion dollar agreement for the transfer of natural gas to Turkey for a period of 22 years. The contract included the construction of a pipeline from Tabriz, northwestern Iran to Ankara for the transfer of nine billion m^3 of gas annually. This contract is confronted with a different set of problems, most seriously being the political relations with the U.S.

The other agreement includes the construction of a gas pipeline to Pakistan which was supposed to start in October 1996. It will take four years to construct the two billion dollar pipeline which once completed will carry 16.5 billion m^3 of gas per year.

Iran and Turkmenistan have entered several agreements for the transfer of natural gas. Construction work was already started in August 1995 on a 200 km pipeline which connects the gas networks of the two countries. The purpose of this contract was to supply the natural gas to the Iranian northern cities and to export heavy oil and gasoline to Turkmenistan from

[14] Liquified Natural Gas
[15] Million cubic meters per day

the Iranian southern ports on the Persian Gulf. In December 1997, the first natural gas began flowing through a relatively small pipeline from Turkmenistan's southern Korpedze gas field to Kurt-Kui in Iran. The line, which was financed by Iran (80%) and the Turkmen government (20%), has an installed capacity of 7.4 billion m³ per year.

- ***Coal***

The production of coal began early in 1960 in Iran. Due to the abundance of oil and gas reserves, coal has played an insignificant role in the Iranian energy sector. The consumption of coal in Iran is dominated by the steel industries. It is estimated that the total capacity of coal reserves in Iran reaches about 12.3 Gt. As shown in Table 1-3, the coal reserves are spread over almost five main basins. The majority of the country's coal reserves are located in the Alborz Mountains and the northeast of the country. About 44.7 % of Iran’s coal reserves are metallurgical coking coal used for the steel industries. The remaining 55.3% includes thermal steam coal, which is exported to countries as Azerbaijan, Armenia, Turkey, Kuwait, Indian and Syria. The total number of coal mines amounts to 77 [104].

Table 1-3: The Coal Reserves in Iran (Mt) [193]

Region	Total Coal Reserves	Metallurgical Coke	Bituminous
Alborz	3318	2220	1098
Kerman	875	373	502
North-east Khorasan	8316	4209	4204
Isfahan	100	100	-
East Azerbaijan	150	150	-
Total	12,759	7052	5707

The Babnizou und Pabedana coal mines, near Kerman, and the other mines around Shahroud, all operated by National Iranian Steel Co., supply about 65% of the coking coal in Iran’s steel industry. The imported coal satisfies the local demand of coking coal. In 1998, more than 80,000 t out of 1.6 Mt of coal used in the country were imported. A major new underground coal mine at Tabas, 300 km northeast of Yazd city, is being considered for development;

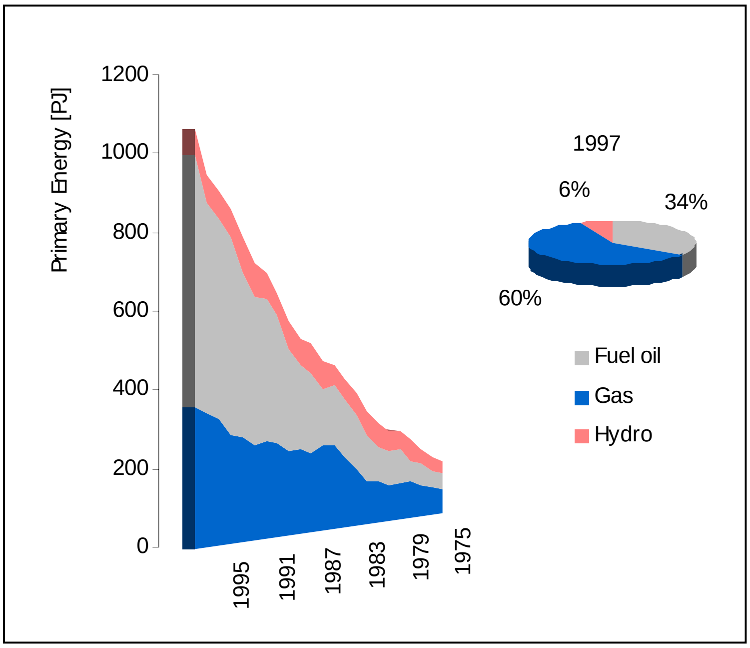
however, inadequate infrastructure coupled with the scarcity of foreign exchange prohibits immediate development. The project would necessitate the construction of access roads, an airport, a 100 km water pipeline, and 200 km of railway. This mine is projected to have a production capacity of 3.5 Mt/yr [85].

- ***Electric Power***

The power sector of Iran, which is responsible for the supply of electricity, is undergoing evolutionary changes. The Iranian electricity industry was formally set up with the establishment of the Iran Electricity Organisation in 1962 which became the Ministry of Water and Electricity, renamed the Ministry of Energy in 1974. Today, the electric power is produced, dispatched, transferred, and distributed by the Tavanir Company affiliated to the Ministry of Energy.

As a consequence of economical and social development and the population growth in Iran, the demand for electricity is increasing rapidly. In 1999, Iran had more than 60 power plants and a power generating capacity of 25,500 MW. During the past 20 years, the installed capacity has grown by an average of 3.7%. The country's electricity output with an average 6.32% growth ranged from about 17.4 TWh in 1979 to 102 TWh in 1999.

Figure 1-9: The Consumption of Primary Energy in the Electric Power Plants [193]



The number of power subscribers has shown a four-fold increase over the past 20 years, at about 14 million in 1999, whereas it was 3.4 million in 1979. This means 98% of the population have access to the electricity. The remaining 2% refers to the villages that are far from electricity grids or have a low population. The number of villages accessed to electricity reached from 4,327 in 1979 to 39,100 by the end of 1999 i.e. a 9.5% growth yearly. The length of power distribution lines rose to about 398 thousand km in 1999 from 56 thousand km in 1979.

As Figure 1-9 shows, most generated electricity is based on the combustion of fuel oil and natural gas. More than 90% of Iran's electricity is produced in thermal plants and almost all the rest is generated in hydroelectric facilities. In 1997, the steam turbine power plants generated about 66 TWh electricity. These plants were the largest electricity producer with a share of about 71% followed by the combined cycle power plants with a share of 13.2%, the gas turbine power plants with a share of 7.6% and finally the hydroelectric power plants with a share of 7.4%. Diesel power plants with 474 GWh electricity generation have played an insignificant role in the electricity sector.

The steam turbine power plants operate with a total capacity of 12,690 MW, the gas turbine power plants with 7,613 MW, the hydroelectric power plants with 1,960 MW, the combined cycle power plants with 1,798 MW and the diesel power plants with 400 MW. The capacity of the fossil fuel power plants increased from about 3636 MW in 1975 to about 23,000 MW, i.e. 92% of the total power plant capacity. Hydroelectric power plants have a small share in electricity production. In 1997, more than 8000[16] MW of the hydroelectric generation capacity was under construction [192] (see Figure 1-10) as well as more than 5500 MW of the thermal power plants.

In 1997, for the production of 85 TWh of electricity, 1.04 billion liters gas oil, 7.4 billion liters fuel oil and 13.4 billion m^3 natural gas were consumed. The usage of gas is replacing fuel oil and gas oil gradually so that the consumption of gas oil in power plants has sunk from 20.7% to 4.6% during the past 20 years.

Surplus of generated electricity in the Iranian power plants is exported to the neighboring countries. At the end of 1999, Iran had exported 235 MW of electricity to its neighboring countries and there are plans to double this in future. The Iranian electricity network is

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16 - Karun I: Capacity of existing power plant is 1000 MW, after finishing of erection of extention capacity will be 2000 MW, average annual power generation is 4000 GWh
- Karun III: With a capacity of 2000 MW, after finishing of erection of extention capacity will be 3000 MW, average annual power generation is 4137 GWh
- Karkheh: Capacity of existing power plant is 400 MW, average annual power generation is 934 GWh
- Masjed-e-solyman: Capacity of existing power plant is 1000 MW, after finishing of erection of extention capacity will be 2000 MW, average annual power generation is 3700 GWh

connected to Turkey, Azerbaijan, and Armenia. A project is to be implemented in the near future to connect Iran to Turkmenistan. From the total electricity generation capacity, 40 MW have been used to supply to Turkey, 150 MW to Armenia, and 45 MW to Nakhichevan and Azerbaijan. Iran also aims to use 20 MW of electricity capacity in order to export to Pakistan and to raise it to 50 MW by 2006. This agreement has not been signed yet because of U.S. policies and its pressures on Pakistan. Iran has a policy according to which it sells or transacts electricity with its neighboring countries and through this policy it has a seasonal exchange of electricity. This means, during the summer, Iran's electricity consumption reaches its climax and therefore it imports electricity from Armenia but in the winter it is vice versa.

Figure 1-10 The Hydroelectric Power Plant under Construction in south of Iran [50]

Iran plans to use 50 MW of electricity capacity in order to export to Turkmenistan and Turkey. The project for the transit of Turkmen electricity via the networks of Iran and Turkey was approved in principle by the governments of the three countries in 1995. A

Turkmenistan-Iranian electricity transmission line was planned to operate at the end of 1999. The operations to connect the Turkmenistan-Iran power network are almost over but Turkey has yet to complete operations for a similar power network connection with Iran. Presently 25 MW of electricity capacity is used with the purpose of export. The Turkmen and Turkish parties agreed on an initial purchase and sale of 750 GWh of electricity per annum. There are also plans to export electricity to Afghanistan and Pakistan in the next 10 years.

Iran's annual power consumption is growing at a rate of 7.5%, which is equivalent to an additional 1,600 MW in capacity each year. To meet the shortage, several power plants are under construction to produce 12,000 MW of electricity. The power generation capacity of power plants is to increase by 12,700 MW in the Third Five-Year Economic Development Plan (2000-2005) to 35,206 MW. It is estimated that a two billion dollar investment in the field of production of energy is annually required to meet the growing trend of electricity consumption in the country [192]. The volume of investment in the sector does not correspond to the current growth in electricity consumption and should be increased at least by 1.5 times.

As part of the continuing move from a centralised system towards a market-orientated economy, Iran has had to confront the need for institutional and regulatory reforms of the power sector. For improvement of this sector objectives were pursued based on: increasing the reliability of the power supply; upgrading efficiency by both decreasing internal consumption by the power generation system and reducing power loss; achieving consumption management; optimising the fuel consumption of thermal power plant; saving energy; privatisation and expansion of hydroelectric and combined cycle power stations.

- ***Hydro Power***

The total capacity of water resources in Iran is estimated at 128.5 km^3/year. The surface runoff represents a total of 97.3 km^3/year, of which 5.4 km^3/year comes from drainage of the aquifers. The groundwater recharge is estimated at about 49.3 km^3/year, of which 12.7 km^3/year is obtained from infiltration in the riverbed. Iran receives 6.7 km^3/year of its surface water from Afghanistan through the Helmand River. The flow of the Arax River, at the border with Azerbaijan, is estimated at 4.63 km^3/year [60].

The total agricultural, residential/commercial, and industrial water withdrawal was estimated at about 70 km^3 in 1993. This is equal to 51% of the actual available water resources. Further to these 70 km^3, another 39 km^3 of water is used annually, of which about 20 km^3 are used for electricity production [60], 11 km^3 for flood control, 2 km^3 for environmental protection (control of downstream parts of rivers), while the remainder is considered to be surplus water. The largest rivers include: Karun (890 km), Sefidrood (765 km), Karkheh (755 km), Mand

(685 km), Qara-Chey (540 km), Atrak (535 km), Dez (515 km), Hendijan (488 km), Jovein (440 km), Jarahi (438 km), Zayandehrood (405 km). All streams are seasonal and variable [81].

The long-term objective of Iran's water resources development plan is based on the control and regulation of water resources through dams. In 1997, 27 storage dams were in operation with a capacity of more than 1999 MW and they account for 8.5% of the total electricity production capacity in Iran. The annual electricity production from dams was 6908 GWh, which accounted for 7.4% of the total electricity production of the country in 1997.

Eight hydroelectric power plants with a capacity of 8,000 MW already under construction in the different parts of country will gradually become operational by the year 2006. The largest hydropower plant is the 7,600[17] MW Karun power plant on the Karun River in the southwest of Iran. The plant is being up scaled to 10,080 MW, which will thereby improve the share of hydropower generation in total electricity production by 39%. According to the schedule of the Ministry of Energy, 23 dams were being built in Iran between 1996-2000 which once completed will raise the number of new dams built in the country since 1996 to 35. Most of these dams are small, but three dams now under construction are considered among the largest dams in the world. These dams include ([192][193]):

The largest hydroelectric project on tap is the 2,000 MW Karun IV Power Plant (Godar-e-Landar), scheduled for completion by 2001. It is located approximately 25 km northeast of Masjed Soleiman on the Karun River. The project dam, which is being funded by the state budget and by loans from Japan, will generate 3,700 GWh of electricity annually. The total cost of the dam amounts to three billion dollars and the domestic companies are responsible for 55% of construction operations.

The other large hydro power plant on the Karun River (Karun III) is scheduled for completion by the end of the year 2002. With the construction of this project around 3000 MW of electricity will be added to the nationwide power grid. The dam, which is 191 m high produces approximately 4137 GWh of electricity annually. Some 3 billion m³ of water from this dam will be used to irrigate farmlands in the area.

Karkheh storage dam and its hydroelectric power plant are located 20 km northwest of Andimeshk. The aim of this project includes the storage of shallow waters for the irrigation of about 320,000 ha of land in the provinces Ilam and Khuzestan, generating 933 GWh electricity annually, controlling destructive season floods, and developing lateral industries.

[17] Include Karun I (2000 MW), Karun II (600), Karun III (3000 MW), Karun IV (1000 MW), Karun V (1000 MW) on the Karun River. The Karun River from Iran joins the Shatt at Basra, and they empty into the Persian Gulf altogether
Karun I is in operation, Karun III and Karun IV are still under construction, Karun II is under design and Karun V is under study.

The dam with 3 units of 133.3 MW each has a total electricity generation capacity of 400 MW.

- ***Nuclear***

The plan to construct nuclear power plants stemmed from the policy of development of non-fossil energy sources. Iran’s nuclear energy plan has been a matter of controversy both inland and abroad. The United States in particular has argued that with sufficient oil and gas reserves for power generation Iran needs no expensive nuclear reactors and considers there is a probability of their use for military purposes.

Construction of the first nuclear plant began in 1974 by German contractors, but was stopped following the Islamic Revolution in 1979 with 80% completion. Work ceased again in 1982 as a result of a fire in the plant and additional damage from three Iraqi attacks in 1985-86 for the third time. The plants under consideration were pressurized water reactors using enriched uranium and were built near the Persian Gulf because of the need for large quantities of water for the cooling system.

In 1995, Iran secured a US$780 million contract with Russian Ministry of Atomic Energy to complete the facility. The contract entered into force on January 1996 and requires for the reactor to be completed within 55 months. Russia plans to install pressurized-light water (VVER-1000) reactor with four vertical steam generators. It was estimated that the plant could be completed by 2003. For the above mentioned reasons, the United States strongly opposes the project and has provided Russia with information pointing to the existence of an Iranian nuclear weapons program ([187][191]).

Despite the United States’ sanctions, Iran plans to meet 20% of the country's electricity demand through nuclear power and has decided to add another 1,000 MW reactor to the station, or build a completely new plant. Iran has been discussing further nuclear power plant deals with Russia and China. Russia might expand its nuclear trade with Iran to include heavy water reactor. Iran has been negotiating with China on building a 300 MW reactor [45] in the southern Persian Gulf.

- ***Renewables***

Iran has the benefit of considerable potential to take advantage of renewable energy such as wind, solar and geothermal. It is planed to generate a capacity of 32 MW electricity from this source by the end of 2001.

The extent of solar energy received by Iran is eight times more than its total oil and gas reserves. The average global insolation[18] is estimated to be about 1,800 kWh/m^2 annually for Iran ([39][193][93]). Iran plans to produce 5% of the country's electricity demand by solar energy in the next 25 years. Presently, Iran has solar power plant projects in Tehran, Fars and Yazd with a total capacity of about 200 MW. A feasibility study for implementation of a 100 MW thermal solar power plant[19] [239][139] in the desert of Yazd began in 1994 and the plant will go into operatation in 2005. The photovoltaic power generator with a total capacity of 32 MW in Tehran and Fars is planned to operate in 2001.

According to the studies done by the different organizations in the 26 regions of Iran, a total of 6,500 MW wind turbines could potentially be installed. During 1995-98, about 11 GWh electricity were generated by 10 wind turbines in Rudbar and Mangil in the north of Iran. The total capacity of wind turbines was 3,500 kW by end of 1998. It is planned to reduce the dependency on oil and gas during the next five years by means of introducing at least 100 MW of wind generated power to the electricity network system. Two sites of wind turbines belonging to the Ministry of Energy are already producing 500 kW and 27 other sites with a capacity of 10.1 MW are already under construction.

In 1974, sporadic research on biogas technology was started by 16 research centres across the country which led to the building of about 60 experimental biogas plants. The results of the studies are not sufficient to define whether Iran is likely to adopt biogas technology on a large scale. While during the past three decades, some deforestation has ensued in the northern part of Iran, as trees have been used up for fuel, apart from public health and pollution control in rural areas, biogas technology can be a great benefit in the area of reducing deforestation [118].

The utilization of geothermal energy in Iran began during 1975 and was conducted by an Italian electric company and the Ministry of Energy. In 1990, a new round of activities began with a company from New Zealand to substantiate the feasibility studies into a full scale discovery project at 190 locations in the Meshikin-shahr and Sabalan areas in the north west of Iran. The discoveries have prepared the necessary ground for drilling at high potential sites. Since then, the two sites, Damavand and Azarbaijan have been discovered and studied thoroughly. It is estimated that the reservoir in the above four regions have a resource potential of about 7400 MW of electric power [62].

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[18] Solar insolation is the amount of solar energy received on a surface in kWh/m².

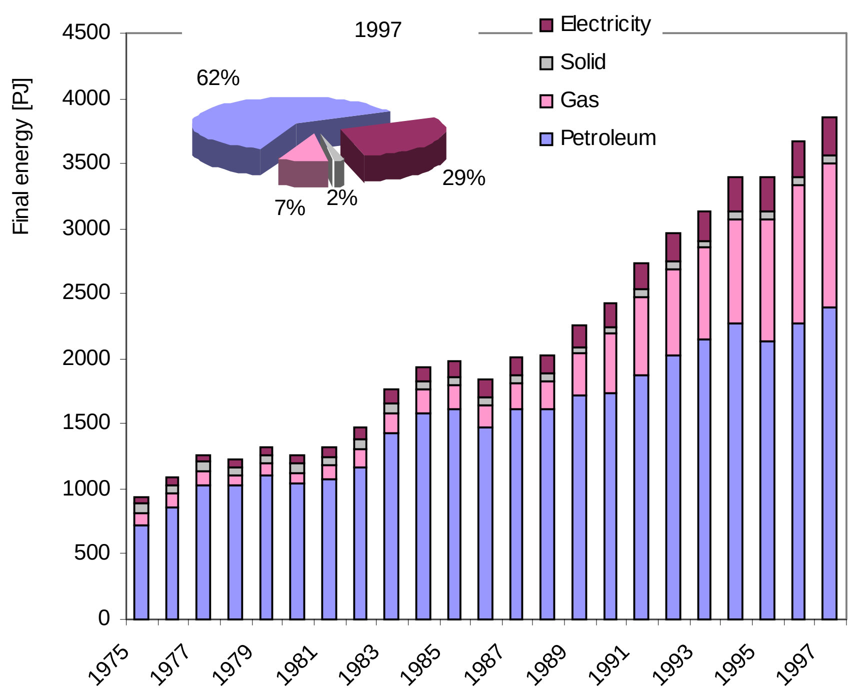
[19] The Solar field is comprised of parabolic trough mirrors and is connected to a natural gas combined cycle power plant. It is planed to use two gas turbine units of 123.4 MW, a waste heat recovery steam generator and a steam of 198 MW for a total installed power of 414 MW. Total net electric power is 2917 GWh. The Solar field is formed by LS-3 by LS-3 parabolic tough collectors ordered in 84 loops, the solar radiation is about 2515 kwh/m² and thermal energy from solar field is almost 470 GWh. The Solar field has been optimized to fulfil the plant requirements and to give solar a contribution of around %5.3.

1.2.2 Energy Consumption in Iran

The final energy consumption in Iran has increased at a high rate in the past 15 years. The annual growth in final energy consumption was 6.4% during the period 1975-97. The large growth in the final energy demand over this period was met by the increased domestic supply of petroleum products and natural gas, whereas solid (coal and fuel wood) energy has played an insignificant role in the total energy consumption. There were two interruptions in the energy consumption growth during this period. The first was in 1981 and the next in 1987 due to the Iran-Iraq war and the damage to the petroleum facilities.

As in most countries, petroleum is the main fuel for meeting the total energy requirements in Iran. Domestic demands for oil derivates grew at an annual rate of 5.8% but its share of total final energy consumption was reduced from 77.2% in 1975 to 62% in 1997 (see Figure 1-11). The transportation sector accounts for about 38% of the demand for oil products in Iran followed by the residential/commercial sector, which accounts for nearly 30%. While the industry and agriculture sectors have a share of 15% and 6.5% of the total energy consumption respectively. The consumption of oil products in the transportation sector increased from 238 PJ in 1975 to 920 PJ in 1997, showing a consumption growth by four times. Over the same period, the residential/commercial sector with an increase in consumption from 233 PJ to 721 PJ about had the same growth as the transportation sector.

Figure 1-11: The Final Energy Consumption in Iran [193]



Natural gas is considered as a favored fuel in the Iranian energy sector and its consumption is increasing sharply. The consumption of natural gas increased from 92 PJ in 1975 to 1111 PJ in 1997. That means it grew at more than 13% annually and in 1997 contributed 29% of the total energy consumption. The electricity sector is the largest domestic gas consumer in Iran, consuming about 39.4% of the total domestic gas consumption in 1997. The gas consumption by the industry sector accounts for about 28% of the total natural gas produced in Iran. The major end-users in the industry sector are the iron and steel industries.

The consumption of gas in the residential/commercial sector amounted to 410 PJ in 1997 and accounted for 32.6% of the total gas consumption. The relatively low consumption in the residential/commercial sector is primarily due to the expansion of gas pipelines. While the most power and large industrial plants are located along the gas pipeline, the largest part of the rural areas far from the gas network pipeline cannot profit from natural gas. Secondly, the household connection charges may discourage poorer households from using natural gas. In 1997, about 4 million households were provided natural gas with the pipeline.

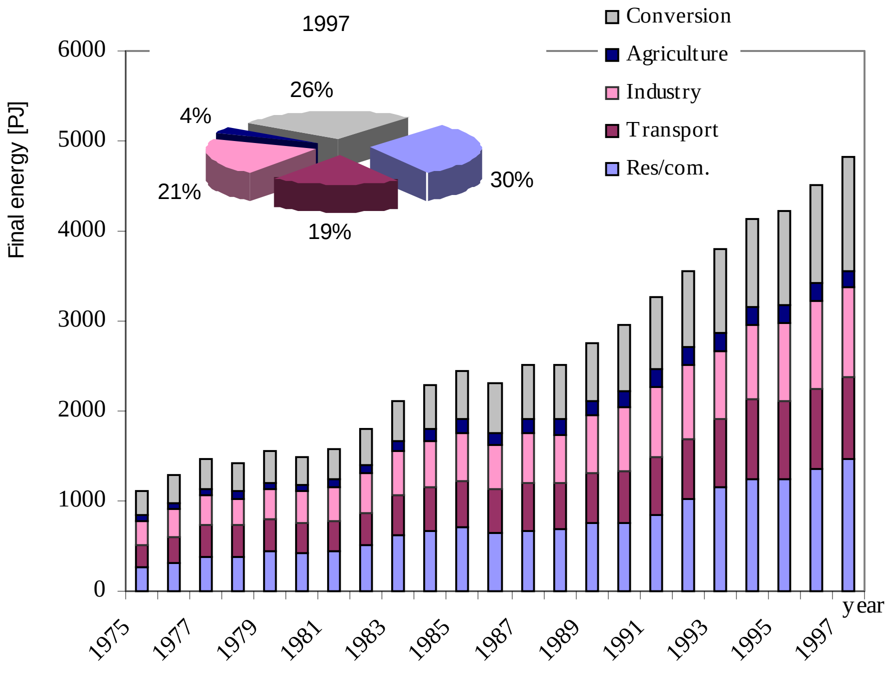
Although the demand of electricity in the end-user sectors grew by 7.3% in 1997, the share of primary energy consumption in the electricity sector amounted to 21% due to the low efficiency of the electricity supply. The national conversion factor of electricity and the loss were about 33% and 20% respectively in power plants and through transmission/distribution. 53.4% of Iran’s total generated electricity is consumed by the residential/commercial sector, followed by the industrial sector with 34% and the agriculture sector with 7.7%. It is estimated that the industry and agriculture sectors will consume 65% to 70% of the total generated electricity in the future.

The high growth of electricity consumption in the residential/commercial sector arises from the population growth in the Iranian cities and the improvement of life in the rural areas. About 4% of electricity consumption comes from the new connection to the electricity network in the rural areas. The electricity consumption in the cities has increased 5.5 times over the last 20 years, while the demand in the rural areas has increased nine-fold over the same period.

76% of the total energy consumption in 1997 (4832 PJ) met the energy demand of the end-user sector and the remaining 26% was used in the energy conversion sector such as electric utilities, petroleum refining, etc (As shown in Figure 1-12). A breakdown of the final energy consumption in 1997 shows that 30% energy was used in the residential/commercial sector, 21% in the industrial sector, 19% in the transportation sector and 4% in the agricultural sector. The residential/commercial sector is the largest energy-consuming sector, followed by the transport and industry sectors. Considering the economic structure in Iran and the population growth, this composition is not surprising.

The highest growth in energy consumption concerns the residential/commercial sector with the increasing connection to the electricity nets and the use of home appliances, and the expansion of the commercial sector. This sector is characterized by an extravagant use of energy. The pattern of energy consumption shows that urban families use more heat in the winter and more refrigeration in summer than equivalent families in other countries. Moreover the population growth as well as the rapid rate of urbanization has lead to an increased demand for oil products and natural gas. The other reason for the rapid increase in energy consumption is the government policy of setting low energy prices. From 1980 to 1990, while the prices of consumer goods rose by 4.7 times (16.7% annually growth), the prices for electricity rose by only 1.9 times.

Figure 1-12: The Final Energy Consumption by Sector [193]



As pointed out before, the function of the industrial sector strongly depends on the oil income and the foreign currency. Industrial production is reduced when the economy is confronted with a deficit of foreign currency and a decrease in imported raw materials. The relatively low energy growth rate in the industrial sector was due to the low output growth in this sector during the 1980s when production material and parts were scarce. The largest energy consuming industries in Iran are the steel, construction, aluminum, chemical fertilizer and petrochemical industries, designed on the basis of the availability of plenty and cheap energy.

The share of the transportation sector in the final energy consumption decreased from 21% in 1975 to 19% in 1997. In spite of the reduction in its share in the total energy usage, it had 6.6% growth annually during the above-mentioned period. The old technology of cars and the low energy prices have caused more consumption of fuel in this sector.

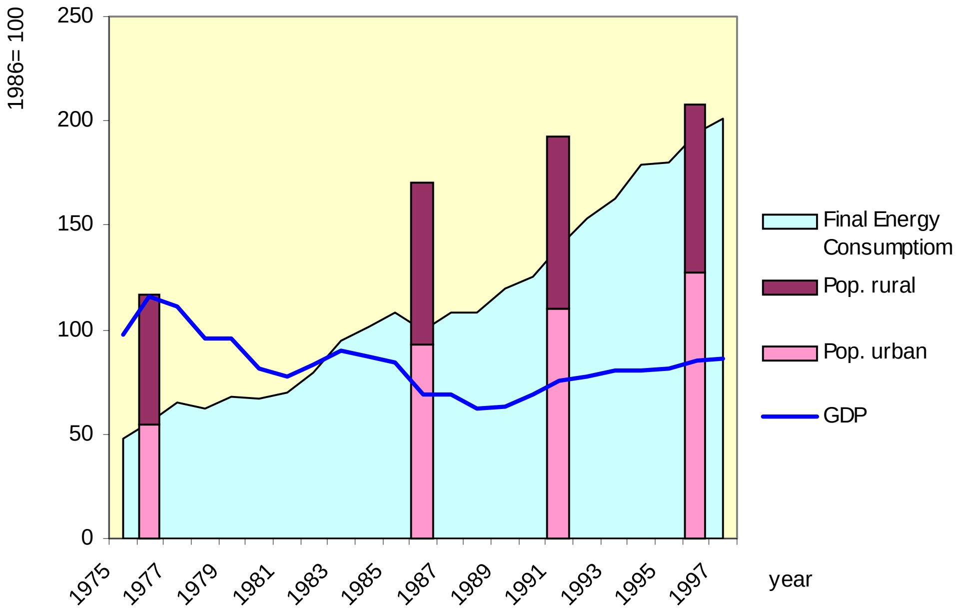
Although the energy consumption in the agricultural sector has risen by 10-fold over the past 16 years, this sector is still the lowest final energy consumer. The major energy consumer in the agriculture sector is the pumping facilities on farms with a share of 38%. Energy consumed for fertilizing the farmland is calculated to be the next highest amounting to 36%. The remaining 24% of energy consumption is for the seeding and harvesting processes.

- ***Energy Demand in Iran***

As Figure 1-13 shows, the total energy consumption in Iran indicates an upward trend, but its growth in various periods has differed. The energy consumption has increased at an average annual rate of 6.4% over the period 1975-97. The total consumption rose from 840 PJ in 1975 to 3554 PJ in 1997. In the same period, the gross domestic product fluctuated. The difference in the annual rate of energy consumption is due to a decline in the GDP i.e. in those periods. When the GDP grows, energy consumption grows at a higher rate, while in the periods of decline of the GDP, energy consumption grows at a lower rate. The growth of the final energy consumption was significantly higher than the GDP growth during this period. The average annual growth rate of the GDP was 1.7% [20]. This indicates that the effect of the GDP on the energy consumption has been small. As mentioned before, the relation between the rate of GDP growth and energy consumption reveals that GDP growth in Iran depends on the amount of foreign currency revenue obtained from exported oil and oil price.

Between 1975-1997 the energy consumption per capita increased, but the per capita GDP almost decreased, the per capita consumption of energy increased from 41 GJ in 1975 to 63 GJ, while the per capita GDP at the fixed prices of 1975 decreased from 281,480 Rials in 1975 to 247,000 Rials in 1997. There was consistent substantial growth of the energy consumption during the 1970s and 1980s. The economy underwent considerable fluctuations and the real national income has still not overtaken the peak reached in 1976. Even during the period of economic stagnancy due to the war with Iraq, the energy demand in Iran continued to increase steadily. Considering the fact that energy has been under price controls in the past decades, the increasing trends of population and the total energy consumption show that the changes in the population play a significant role in the growth of energy consumption.

Figure 1-13: The Primary Energy Consumption and GDP in Iran [193]



In 1975, out of a total energy consumption of 979 PJ, 372 PJ were consumed by the industrial and agricultural sectors. So the energy share of industry and agriculture was about 38%. In 1997 the total energy consumption was 3571 PJ, of which 1126 PJ were used by the industrial and agricultural sectors. It shows that the share of industry and agriculture has decreased compared to 1975. Therefore the residential/commercial, and transportation sectors with about 60% share of the energy consumption are the main consumers of energy. The reasons can be found in the population growth and the increasing urbanization, which have enlarged the residential sector and increased the energy consumption further. This sector becomes increasingly energy intensive with growing incomes and increased urbanization. During the past 20 years, the urban population has grown by two times, while the rural population has not changed much in the same period. These show that energy consumption has a strong correlation with the population.

The services provided by the transportation sector may be utilized both as consumer goods and a factor of production. In the Iranian economy these services are mainly consumer goods. That part of the transportation sector which provides the consumer services, expands with the growth of population, in turn increasing the energy consumption. Hence there is a weak correlation between the energy consumption and the GDP in the Iranian economy.

Not enough attention has been paid to energy resource management and planning has been carried out simply and on the basis of past trends. The official forecast for the energy demand is released by the Plan and Budget Organization for the Five Year Development Plan. Recently, some studies have been implemented by the Ministry of Energy, Ministry of Oil and Atomic Energy Organization, which have considered different assumptions to project energy demand. These assumptions and results are described as follow:

Table 1-4 shows the results of the studies done by the Ministry of Energy for the short-term energy demand planning. Considering that energy has been supplied at a lower price in Iran, four scenarios have been taken into account and the effect of energy prices on the final consumption has been analyzed. In the first scenario, it has been assumed that the energy price rise is 20% as in the Second Five Year Development Plan and that the GDP grows at 6% annually rate. The energy intensity ranges from 40.5 million barrels oil in 2000 to 42 million oil barrels in 2005 and the final energy demand grows from 817 million barrels oil to 1055 million barrels oil in 2005. As a result, the energy demand increases 7.2% annually. In scenario B, the energy prices rise gradually to reach the real price during the planning period. The average growth rate of the energy demand will be 4.3%. In scenario C, the energy price reaches the real costs during the first year of the planning period. This rapid rise decreases the average growth rate to 2,6% yearly. The final scenario is a combination of B and C resulting in 4,1% growth in the energy demand.

Table 1-4: Forecast of Final Energy Consumption in Iran, 2000-2004 (PJ) [117]

Scenarios	2000	2001	2002	2003	2004	Average growth rate
A	4999	5336	5642	6033	6456	7.2
B	4895	5152	5360	5519	5599	4.3
C	4479	4534	4687	4895	5158	2,6
D	4877	5115	5324	5470	5562	4,1

Table 1-5 shows the forecast of the oil and gas demand in Iran between 1996-2026 by the National Iranian Oil Company [64]. In this estimation, it has been supposed that the rapid growth of urbanization and the industrial development will increase the demand for oil products and natural gas in the medium and long term. It has been also suggested that the gas demand in the residential/commercial sector will increase to 555 PJ by 2000. Similarly, the gas demand in the industry sector will increase to 566 PJ and in the power generation to 648 PJ by 2000. The annual growth rate of the population is assumed to be 1.2% up to 2026.

According to the projection, the oil demand in 2026 will be two times as high as in 1996, corresponding to an average annual growth rate of 1.4%. The gas demand will grow at an average annual rate of 7.5% between 1996-2006. The high growth during the first ten years is due to the development of gas network pipelines in the rural areas and for industry and power plants, which are located far from the gas network. The growth in the gas demand has been considered 4.3% for next ten years.

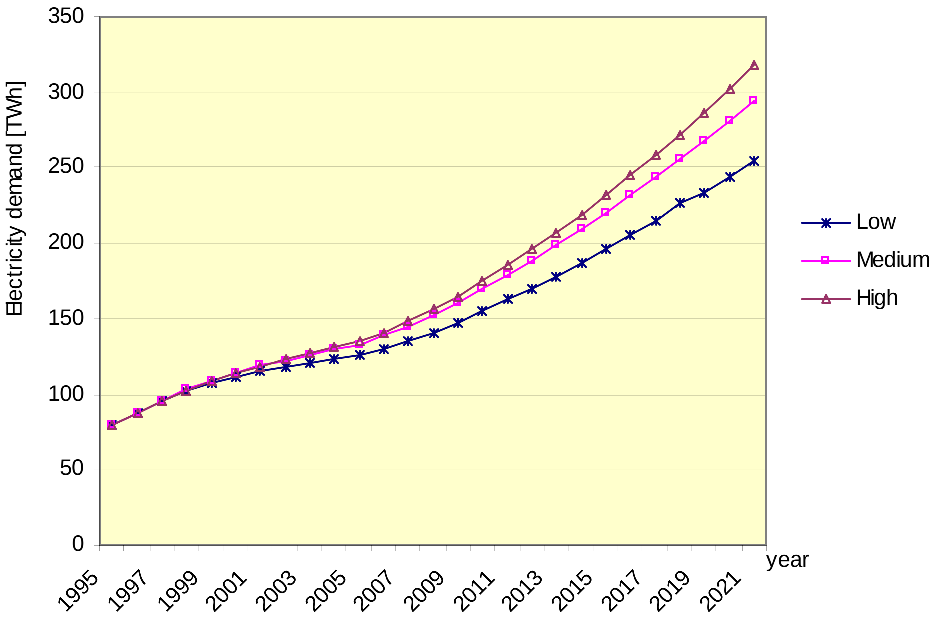
Table 1-5: The Forecast of the Petroleum and Gas demand in Iran, 1996-2026 [64]

	Unit	1996	2001	2006	2011	2016	2021	2026
Oil	PJ	3040	3274	3527	3799	4094	4409	4751
Gas	PJ	1675	2669	4257	5434	6935	8849	11294
Population	million	60	63.6	67.6	71.6	76.1	80.7	85.7

The other study carried out by the Atomic Energy Organization has projected the demand of electricity by an econometric model for the period 1995 to 2021. As shown in Figure 1-14, three different scenarios have been defined, low, medium and high, reflecting different assumptions on the growth of the GDP, the increase of population and the change in electricity prices. The average GDP growth rate is considered to be 6% for the high growth scenario and 5.5%, 4.8% for the medium and low growth scenarios, respectively. The GDP growth scenario is to be considered more than the projection of the Global Energy Council for the Middle East and south Asian countries (4.5%) even in the low growth scenario. The electricity price is assumed to increase at a rate of 7% annually up to 2005, that is higher than the inflation growth rate. From 2005 to 2021, prices will rise at a rate of 2%. Considering the prognosis of the Plan and Budget Organization, the annual population growth is supposed to be 1.73% up to 2006 and 1.5% for the remaining period.

This analysis shows that the electricity demand for the medium growth scenario in 2021 will be between three and four times as high as in 1995, corresponding to an average annual growth rate of 2.5% and 2.7% respectively. That means, an acceleration in the growth of energy demand is expected even in the low growth scenario.

Figure 1-14: The Forecast of the Electricity demand in Iran, 1995-2021 [91]



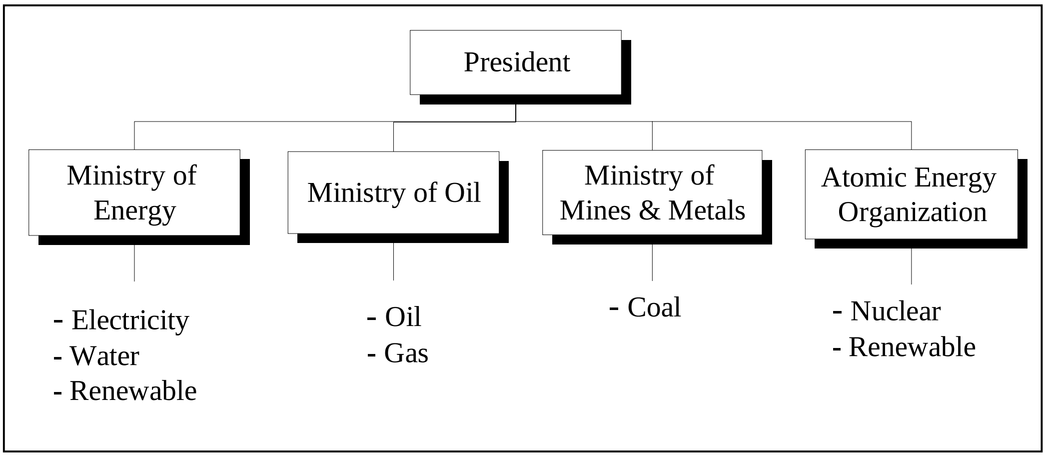
1.2.3 Institutional Structure of the Energy Sector

As Figure 1-15 shows, the main duties of four governmental institutions are to follow the developments in the energy sector, facilitate investments, and to establish energy policies. The most important of them is the Ministry of Petroleum that is in charge of all operations relating to the exploration, production, transport, refinement, sale, and distribution of oil and gas in Iran.

The Ministry of Energy has two responsibilities in the field of energy supplies and water resources. The Ministry is responsible for all activities related to the production, transport, distribution and sale of electricity. In the field of irrigation, it is in charge of the construction of large hydraulic works, including dams and primary and secondary irrigation and drainage canals for the distribution of water. Fourteen publicly owned Regional Water Authorities are responsible for feasibility studies, project execution, and subsequent management.

The overall management of the mineral sector is under the supervision of the Ministry of Mines and Metals. The Ministry's authority covers all mining, smelting and refining industries except oil and gas.

Figure 1-15: Institutional Structure of the Energy Sector



The Atomic Energy Organization of Iran, set up in 1973 to produce nuclear energy for electricity requirements, focused in 1987 on the exploration and use of uranium deposits and on the use of nuclear energy and radionucleus in industry, agriculture[20], and medicine [187].

1.2.4 Energy Policy and Strategy

The energy policies and strategies in Iran can be divided into the two categories, domestic, and foreign policy. The basic goal of Iran's domestic energy policy is to:

- attain economic growth,
- obtain more foreign currency for the financing of the future economic growth and development through energy exports,
- obtain access to new technologies in order to satisfy growing domestic demand,
- increase supply security for various industries.

Despite the high growth of energy intensity in Iran, resulting in significant environmental and economic problems in the large cities, environmental protection has always played a subordinate role in the political scene of the country.

[20] Fertilisers are expensive and if not properly used can damage the environment. Efficient use of fertilisers is therefore of concern to both developing and developed countries. It is important that as much of the fertiliser as possible finds its way into plants and that the minimum is lost to the environment. Fertilisers 'labelled' with a radioactive isotope, such as nitrogen-15 and phosphorus-32 provide a means of finding out how much is taken up by the plant and how much is lost [URANIUM INFORMATION CENTRE Ltd.].

Energy consumption needs to grow consistently in Iran for a recovery in economic activities and to change people's lifestyles, particularly with regard to the increase in the size of home electronics appliances and cars. In terms of demand, the outlook is that the annual energy consumption growth has been kept at about 6% until the year 2005. Considering that energy is produced and consumed with low levels of efficiency, the consumption rate can be cut down by one third through using suitable policies in the different sectors [236]. Low energy efficiency in the country is due to parameters such as: subsidized fuel and electricity prices, absence of competitive market forces, local technical knowledge and suppliers of energy-efficient options, specific efficiency incentives, such as mandated energy performance codes and standards for industry and transport.

One of the most important policies is to limit energy demand through pricing based on economic costs and removing subsidies for energy production and use. The fuel and electricity prices in Iran have been highly subsidized, so that low energy prices, relative to world prices as well as relative to prices in most other developing countries, have not provided sufficient incentives for conservation. According to an evaluation of the Ministry of Energy subsidies amount to more than 30 trillion Rials annually. Subsidizing the price of energy and consequently high consumption has had negative economic and environment results. Low prices give rise to excessive demands and reduce the ability of utilities to provide and maintain supplies. Although the government has implemented a policy of gradual price increases it had little impact, and there has been no change in the pattern of energy use due to the higher inflation rate.

For the purpose of efficient energy consumption, conservation measures must be introduced in all areas, manufacturing, residential/commercial use, and transportation, where there is an opportunity for a stronger energy-saving effort. A first and simple step toward energy conservation in the household sector could be to raise public awareness. To increase public awareness on energy conservation and promote specific energy conservation measures, the government can step up publicity through official bulletins, newspapers, magazines, television, and other publicity channels. However, no fundamental actions have been implemented for strengthening publicity on energy conservation. To expand energy efficiency in the household sector, it is planed to develop standards and enforce them in household electric equipment such as refrigerator, air conditioning, and the insulation of buildings.

One of the large obstacles in the industrial sector for energy conservation is the lack of a competitive market. As mentioned before, the state ownership of most large enterprises prevents energy saving. Recently Iran has moved toward decentralization and privatization in the energy sector. This began with the electricity sector, but due to inadequate execution was not successful. The new law, approved in 1976, obliges the large industries with an energy consumption of more than 5 MW or 5000 m^3 equivalent oil yearly to establish an energy management section. The government also aims to boost the application of an energy conservation law in the industrial sector.

In order to save energy in the transport sector, different policies have been considered such as: reducing street traffic, improvement of equipment and distribution efficiency, substitution of gas-fueled systems in cars instead of gasoline and the development of public transportation systems in large cities.

As oil is the source of more than 80% of its foreign currency income, the other basic goal of the government in the energy sector is to increase of foreign currency through oil exports. In this regard two policies have been pursued. The first is the reduction of oil product consumption to enable the country to export petroleum products. This reduction will be achieved by promoting the use of non-fossil energy sources such as renewable energy, which are acceptable power sources from environmental standpoints, natural gas and nuclear power. The other policy is the development of non-oil exports. Consequently, efforts have been made towards a decreased dependency on oil income.

The primary evaluation shows that the domestic demand for oil products is growing by 6%. On the other side the daily usage is two times the amount of energy products utilized by developing countries. High consumption rate arises from a low oil price, subsidies, old technologies, state ownership etc. If this trend continues, it would be extremely difficult for Iran to earn foreign currency through long-term energy exports. Therefore, Iran must make maximum efforts to greatly decrease oil product consumption. The government has taken some steps to reduce consumption.

The first action was the gradual increase in fuel prices. The average price of fuel in Iran is one eighth of its world price and the annual subsidies for fuel and energy that were paid per capita at the end of the 1994 amounted to 24,000[21] Rials. The price of fuel will have been increased by 20% every year by the end of Second Five-Year Economic Development Plan but it seems that demands will continue to grow. Since 1998 Iran has pursued a policy of modernization and establishment of new refineries in order to prevent losses from old technologies and to discover new oil fields in the country and restructure the oil industry, including decentralization and the separation of policy from executive affairs.

The low efficiency in the energy and industrial sectors as a result of old technologies has caused increasing energy consumption. The lack or inadequacy of technical know-how has prevented Iran from planning and operating rational-use-of-energy measures. In spite of the economic sanctions, Iran has tried to access new technologies to meet these needs. In this

[21] considering the official exchange rate for export, i.e. one U.S. dollar = 3000 Rials, the annual subsidies amounted to US$8 per capita.

regard one of the policies has been the promotion of the establishment of nuclear power generation, although it was not very successful here.

The main target of Iran's foreign energy policy is to achieve the development of energy exports, stabilizing oil prices, attracting foreign investments and accessing modern technologies. To achieve these objectives, the energy policy is focused on the following strategies:

- improvement of economical and political relations with other countries especially with the former Soviet Union
- impact on OPEC’s production policy
- confrontating the negative effect of U.S. sanctions

Following the collapse of the former Soviet Union, Iran has consequently found a new position and the oil and gas rich Caspian region has attracted the interest of the world's oil and gas industries. Iran views the Caspian Sea’s resources as a primary opportunity for diplomatic advancement. Iran can play a very important role in the development of the economies in Central Asian countries because Iran can provide access to international markets through the Persian Gulf. Moreover, Iran can be an alternative route for their oil and gas pipelines to Europe and the Far East. Iran is still pursuing competitive plans for a Caspian oil route with varying degrees of success.

OPEC with 78% of the world's proven oil reserves, can principally act as the most influential factor in stabilizing the oil market. Within OPEC the Persian Gulf countries are the main producers, which have a 70% share of OPEC production. Iran is one of the major Persian Gulf oil exporters, whose oil exports are totally dependent on the security of the Persian Gulf. Under such circumstances, Iran's position within OPEC and the Persian Gulf producers must be considered. Therefore heavy fluctuations in Iran's actual production, which is limited by OPEC policy, can influence the oil price.

The oil sector has always been under political influence. Political difficulties between Iran and the West, sanctions against companies dealing with Iran, have complicated progress in this area. The sanctions have not only barred U.S. companies and reduced the competition among the applicants for buy-back projects in Iran but also made non-U.S. companies reconsider their positions. Iran is trying to develop foreign relations with other countries and to attract their investment for the energy sector.

1.3 Environmental Situation in Iran

The rapid urbanization, population increase, growth of the industry and transportation sectors, and the inefficient consumption patterns have increased concerns with regard to the emission of pollution. Air pollution from the vehicle emissions in the urban areas, refinery operations and industrial effluents, deforestation, overgrazing, desertification, oil pollution in the Persian Gulf, inadequate supplies of potable water are problems throughout Iran, even though the extent and types of problem vary greatly within Iran.

The use of low quality fuel, inefficient methods of the energy production and use, the poor condition of vehicles and traffic congestion are the major reasons for the increasing emissions of SO_x[22] and NO_x in the Iranian cities. The urban environment of Iran is becoming increasingly polluted, with adverse impacts on the health, welfare and productivity of the population. Pollution in Tehran, where 20% of Iran's population lives, has well exceeded safe levels [45][109][18]. Rural areas are threatened by over-exploitation, soil erosion, pollution from agrochemicals and inappropriate land use and management practices.

Although the focus on this study is on the SO_2, NO_x and CO_2 pollution, before describing air pollution in detail, certain other environmental problems will be pointed out.

Iran's climatic and topographical conditions make it particularly susceptible to desertification. Overgrazing, bush picking, wrong irrigation, land use disregarding the land capability, irregular transformation of rangeland to rain-fed farming, non observance of soil conservation in cultivation practices create conditions to reduce biological production and the expansion of desert and arid lands. The area of deserts and sandy soils is about 34 million ha and of the poor and desertified rangelands 12 million ha are sandy soil and 5 million ha are shifting sand dunes. Preliminary estimates show that the desertification growth amounts to nearly 1% annually. Approximately 400,000 ha of fertile soil are lost through erosion every year, causing extensive land degradation and flooding, seriously threatening long-term sustainable agriculture. 45% of the land is already eroded, and only 15% of all the rangelands are classified as being in good condition [61].

The other important environmental problem is water pollution in the Persian Gulf and Caspian Sea. The marine environment in the Persian Gulf has been exposed to various destructive contaminants. The extraction of oil from coastal areas and the continental shelf of the Persian Gulf, coupled with its exports and the passage of oil tankers along the waterway, have had an increasingly destructive impact on marine ecosystems. Estimations show that 40% of the world's total oil transportation passes through the region. The oil sludge, released

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[22] $SO_x = SO_2 + SO_3$

by the total tankers traversing the Persian Gulf, is estimated to be around 8 million metric tons per year. This kind of pollution represents some 60 % of the pollution of this region [240].

The Caspian Sea has been the recipient of various types of polluting substances. The main sources are the industries located around the sea, agricultural activities, oil and gas complexes, and enterprises related to the energy exploration. The studies show that 80% of the pollution stems from the water flowing to the sea from rivers in the west from Azerbaijan [116].

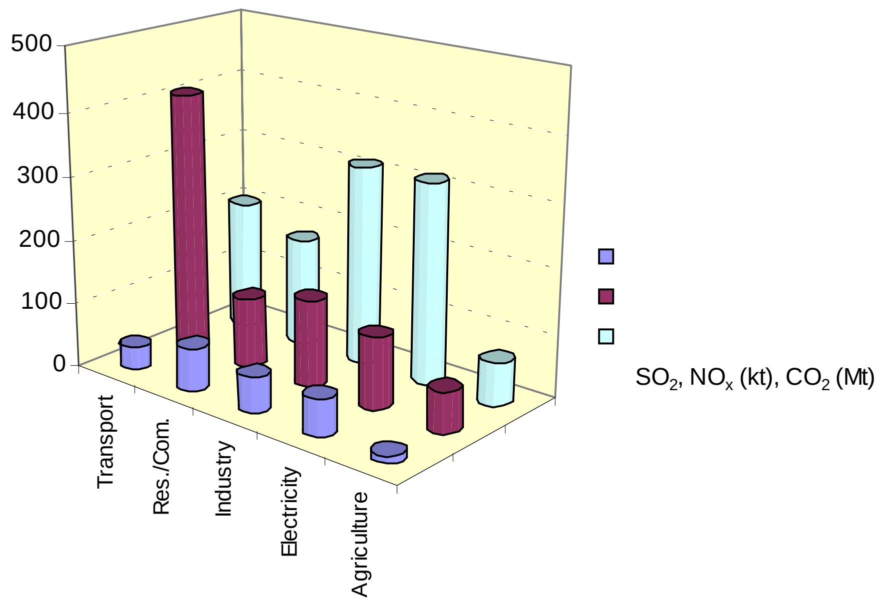
In addition to marine pollution, sustainable management of fresh water resources is an increasing problem in terms of quality and quantity. The rainwater and surface run off, which supplies about 45% of the water demand, is highly seasonal. The water shortages in the summer months lead to unsustainable ground water extraction in many regions. Over 90% of the total water is used in agriculture. Water quality problems are also growing in both rural and urban regions. A further main problem is with the disposal of wastewater from the industrial and residential/commercial sectors. In the urban areas, the polluted water is used for agriculture. The industrial and urban wastewater runoff has contaminated a number of rivers and coastal waters and threatened drinking water supplies.

1.3.1 Air Pollution Situation and Emission Sources in Iran

Heavy industrialization, vehicle use, and urbanization contribute to the air pollution problem in Iran. The poor urban air quality is mainly due to the excessive consumption of more polluting fossil fuels and the use of old and inefficient technology in the industries, especially in the metallurgical and chemical section. Furthermore the industrial policy has been one of import substitution in favor of relatively heavy polluting industries. Overvalued exchange rates and other anti-export policies have also constrained the growth of industries in which Iran may have comparative advantage, such as more labor-intensive industries that are often less polluting. A lack of incentives and adequate training are also problems contributing to inefficient operation and maintenance in industries, which increases air pollution problems. In addition the low energy prices have induced very little incentive to conserve energy and improve efficiency in the industry sector.

Figure 1-16 shows the contribution of pollutants in the different energy sectors. Estimates based on industrial structure, processes, production, sectoral fuel and natural gas consumption in 1997, place total SO_2 emissions at about 1103 kt, NO_x circa 847 kt and CO_2 around 231 Mt. In addition, flaring of natural gas generates a large amount of pollutants of which 370 kt are SO_2 and 20 kt are NO_x [230]. About 55% of these emissions come from the offshore and 45% from the on-shore sources. The on-shore sources are in the Khuzestan province with a population of 3.2 million of which 1.2 million lives in the rural area.

Figure 1-16: The Sectoral Contribution of Different Pollutants (1997) [192]



The largest contributor to SO_2 emissions is the electricity sector. This sector emitted 316 kt SO_2 in 1997 and accounted for about 28% of total SO_2 emissions. Despite the fact that more than 50% of the fuel consumption in this sector is natural gas, some power plants, which have no access to the gas pipeline, use heavy fuel oil with a sulphur content of about 3%, hence causing a higher level of SO_2 emissions from the electricity sector.

Table 1-6: The Metal Smelt Industries in Iran [230]

Industry	Place	Capacity t/yr	Emission control	Emission
Copper smelter	Sar Cheshme	125,700	no	150 NO_x, 125,000 SO_2 t/yr
Lead & Zinc smelter	Zanjan	75,800	yes	
Lead smelters	Tehran	10,000	no	500 t/yr lead
Aluminum smelter	Arak	113,000	no	1,400 particulates, 1,300 SO_2 t/yr
Isfahan Steel Mill (ISM)	Isfahan	4,000,000	no	5,000 SO_2, 200,000 CO, 1,000 NO_x t/yr
Mobarakeh steel complex	Isfahan	1,500,000	yes	

The next large pollutant is industry with circa 315 kt. The high level of SO_2 emissions from the industrial sector arises from refineries and metal smelting industries; about 40% of industrial SO_2 emissions comes from refineries, and about 25% from metal smelters. The remaining 35% is distributed among the remaining industries. As Table 1-6 shows, Iran has three steel works with a capacity of 5.5 Mt/yr. In addition, at least one scrap-based steel plant is in operation in Ahvaz and some are planned or under construction in Azerbaijan, Khorasan, and Yazd with a total production capacity reaching to 16 Mt/yr.

Besides the metallurgical industry, the chemical and petrochemical industries are major air polluters. Iran has seven major refineries in operation with a present capacity of 58 Mt of processed crude oil. SO_2 emissions from the refineries are close to 120 kt/yr [230]. Emissions from the chemical/petrochemical sector are about 24 kt/yr SO_2, 10 kt/yr NO_x, 120 kt/yr CO, and 30 kt/yr NH_3. The most environmentally threatening emission from the chemical sector is mercury.

NO_x emissions per unit of energy from fossil fuels are substantially higher in the transport sector relative to the industrial, agricultural and residential/commercial sectors. About 50% of annual NO_x emissions are from the transport sector. Air pollution from the transport sector is a serious problem in Tehran, in particular NO_x, CO, HC and lead. The average age of private vehicles and bus fleets is more than 15 years with an engine technology from the sixties with a low fuel and emission efficiency. Most of the vehicles in Iran are domestically produced and use more fuel than the cars in the industrialized countries. The production levels of cars have been affected by the exchange rate policy and anti-export bias that have constrained the availability of foreign currency, and thus reduced the industry's access to imported vehicle components. With the low supply of new vehicles, older and more polluting vehicles remain on the roads longer than otherwise. Furthermore, import restrictions have been high in order to protect the domestic automobile industry. This policy has contributed to very limited access to foreign vehicles that are less polluting, and very little incentive for domestic automobile to improve fuel efficiency.

The next largest contributor of NO_x is the industrial sector with a share of about 16% of the total in 1997. The major NO_x pollutants of the industrial sector are 19 cement plants with a total production capacity of 18 Mt per year. The largest plants are located in Tehran and Isfahan. Emissions from the cement plants differ depending on their design and air control equipment and reach 25 kt/yr. Seven refineries form the next major NO_x emissions source with about 10 kt/yr. The electricity sector contributed 13% of total NO_x emissions. Natural gas conversion in the power sector significantly reduced this pollutant.

The residential/commercial sector is the largest energy-consuming sector in Iran, but the fuels consumed are relatively cleaner than those consumed in the industrial and electricity sectors. The increased consumption of natural gas in this sector has reduced air pollution. The shares of the residential/commercial sector in the production of SO_2 and NO_x emissions are about 15% and 13% respectively. However, low energy prices and lack of energy conservation measures have caused a higher level of energy consumption and air pollution.

Figure 1-17: The Shares of CO_2 Emissions (1997) ([33] [43])

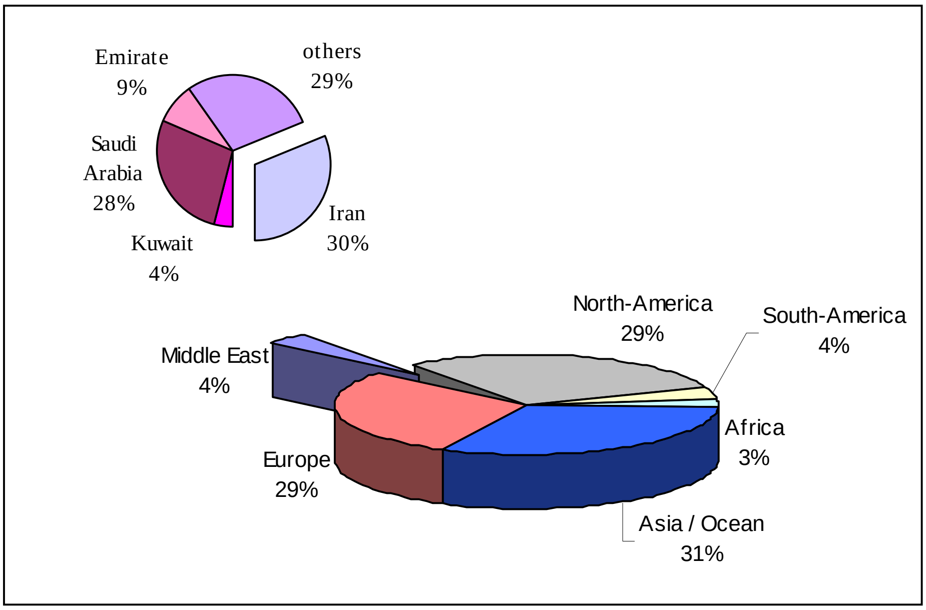


Figure 1-17 shows that the Middle East accounted for 4% of the total world CO_2 in 1997, of which 30% is the share of Iran. However Iran plays a small role in CO_2 emissions production but it generates 46% more CO_2 per unit of output than the global rate, as well as 330% and 480% more than developed countries such as Germany and France, respectively. Low energy prices, perhaps the world's cheapest, have led to a huge energy waste and consequently more pollution.

As shown in Figure 1-16, the residential/commercial sector with a consumption of 36% of the total energy is the largest CO_2 emissions source. Although the consumption of gas has increased in this sector during recent years still 57% of the energy consumption comes from the combustion of heavy fuel oil. The transport sector is the second largest contributor to CO_2 emissions, with about 65 Mt in 1997. The industrial sector accounted for 27% of total CO_2 emitted.

- ***Urban Air Pollution***

The urban population already accounts for 57% of the total country's population. As populations in the urban regions are growing at over 5% per annum, the air pollution could increase in the future years. Therefore preventive and protective actions are required in the large cities also along with better monitoring of air pollution.

Air pollution in most of the major cities is already serious, e.g. the annual average ambient air concentrations in Tehran of SO_2, NO_x, TSP[23] and lead by far exceed the WHO and World Bank guidelines (see Table 1-7) [230]. In other large cities such as Mashhad, Isfahan, and Ahwaz, the concentration of pollution is more than recommended maximum values of the Environmental Health Organization.

Table 1-7: Air Pollution Concentration (annual averages in Tehran 1989-91) [229]

Pollutant	Average Concentrations		% above Guidelines	
			WB[24]	WHO
SO_2	µg/m³	140	40	130-250
NO_2	µg/m³	250	150	
TSP	µg/m³	180	80	100-200
Pb	µg/m³	2.2		120-340

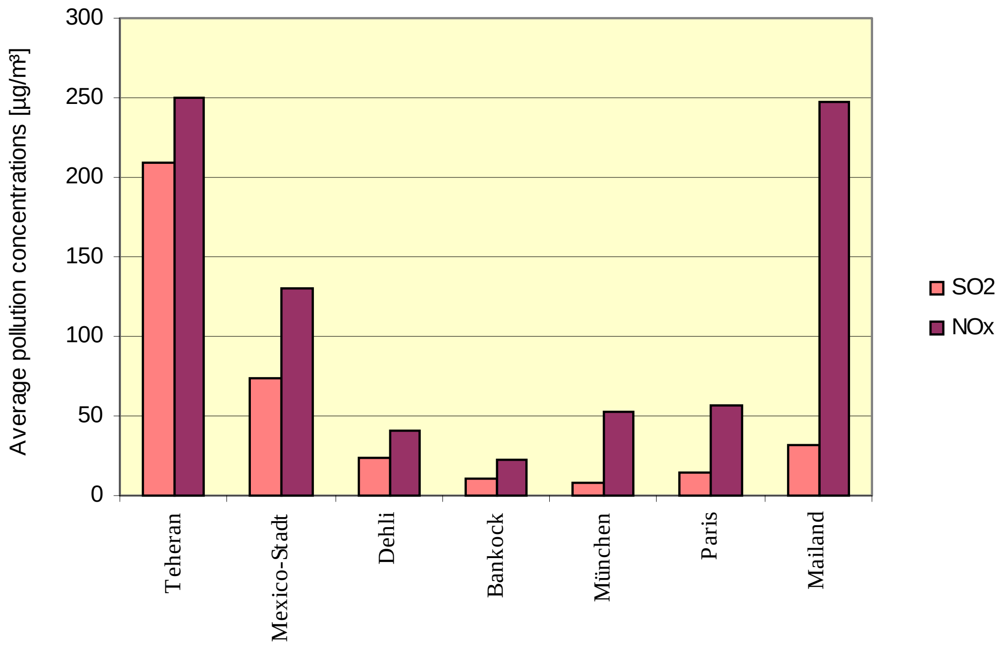
Tehran, a city with 12 million inhabitants (about $^1/_7$ of the country's population) located at the foot of a mountain range which might limit the free circulation of air, is considered one of the most polluted cities in the world, along with Mexico City (Figure 1-18), Bangkok and Jakarta. 60- 70% of the pollution in the Iranian capital is caused by motor vehicles, which consume eight million liters of gasoline per day [95]. Other ancillary factors, include the increase in the population growth, the relative shortage of modes of public transport, the shortage of vehicle spare parts, the relatively advanced age of cars and consequently inefficiency of their engines, low quality of fuels used, such as gas oil and gasoline, and the dryness of the air in Tehran.

In addition to the increase of energy consumption as a result of the accelerated growth of the population in Tehran on the geographical position of the city makes air pollution even worse.

[23] Total Suspended Particulates
[24] World Bank

The city is surrounded by mountains in the north, causing the increasing volume of pollutants to become trapped, floating over Tehran when the wind is not strong enough to blow the pollution away. On the other side, the most polluting industries are placed in the west and southwest of Tehran where the direction of the wind causes pollution to move toward the city.

Figure 1-18: Tehran compared to the Most Polluted Cities in the World (1995) [71]



As Table 1-8 shows, the transport sector with about 56% of the total NO_x emissions was the major contributor in 1996 [116]. Tehran's two million cars alone consume eight million liters of gasoline daily, of which 500,000 cars are over 20 years old with a lack of catalytic converters that filter car exhaust.

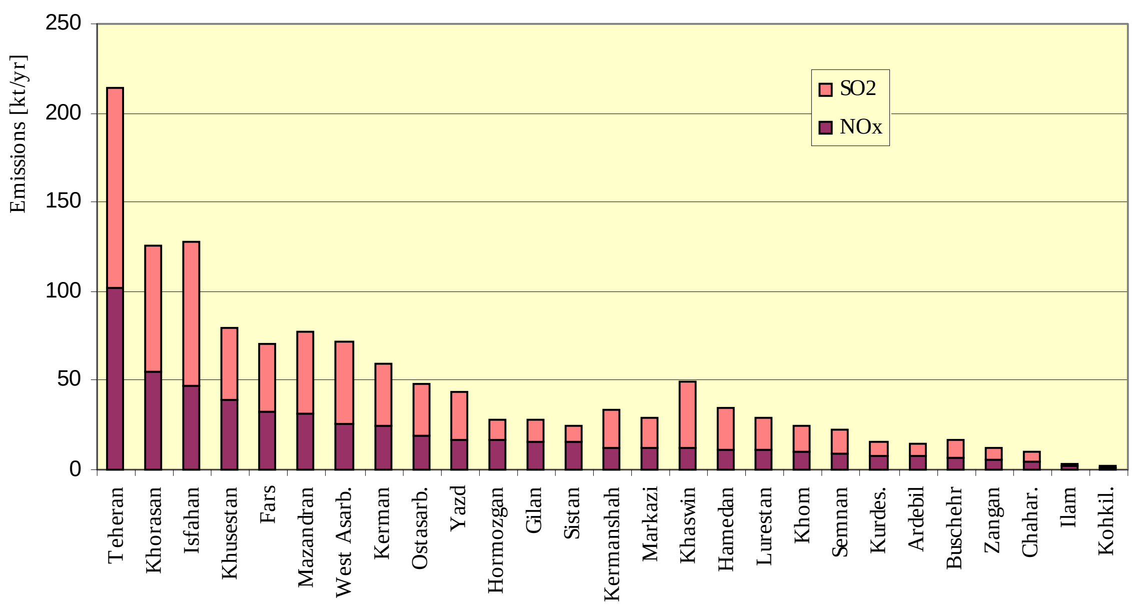
Thereafter the power plants with 30 kt of NO_x emissions have a share of 20%. The concentrations of SO_2 emissions in the flue gas of industries and power plants stem from the consumption of oil fuel with a high sulphur content and gas oil. The industrial and electricity sectors accounted for 54% of the total emitted SO_2 in Tehran in 1996. However, the Tehran refinery releases more SO_2 than all of the vehicle traffic in the city [230].

Table 1-8: The Sectoral Amount of Different Pollutants (t) in Tehran (1996) [115]

Sector	NO_x	SO_2	CO_2
Industry / Electricity	45,229	78,760	16,352,351
Residential / Commercial	20,662	35,951	13,390,871
Transport	84,779	29,404	4,757,694
Agriculture	2,913	3,5951	482,583
Total	153,583	147,101	34,983,499

The heavy pollution is causing fatigue among Tehran's population. It is also causing many problems for people with heart, asthma, skin diseases, itchy eyes and scratchy throats. Sometimes pollution levels reached critical levels, sending untold numbers of citizens to seek medical help. Therefore tens of thousands of Tehran's residents wear masks to protect themselves from the heavy smog. According to the WHO report [232], the combined effect of several pollutants that is greater than merely adding up the effects of individual pollutants, have most high risks for children in cities in Mexico, India, China, Brazil, and Iran.

Figure 1-19: SO_2 and NO_x emissions in the Different States in Iran (1996)



As Figure 1-19 shows, Tehran and the four other cities (Mashhad, Isfahan, Ahwaz and Shiraz) are the most contaminated cities in Iran. Isfahan with about 1.2 million inhabitants is located in the center of Iran, 1400 km from the Persian Gulf on an elevation of 1,600 m above sea level. About 60% of the total population of the province is concentrated in a mere 6% of its total area. Excessive expansion of the urban population and automobiles and the absence of an efficient transport network have turned Isfahan into one of the most polluted cities of Iran. The industries of the city include textiles like cotton, silk and wool; brocade, food and metalwork. Moreover, environmental pollutants in Isfahan's air pose a threat to the historic buildings in the city. Besides human factors, the dry climate, adjacency to deserts and the inversion phenomenon during the cold season, all reduce the natural cleansing of pollutants in Isfahan.

1.3.2 Environment Institutional Framework

The most important organization dealing with environmental issues is the Department of Environment. It was established in 1971, responsible for the protection of the environment and controlling any activity considered damaging to the environment. In addition, it serves as a coordinator, through the Environmental High Council (EHC), among the many Ministries which are charged with the specific aspects of environmental management. EHC decides on environmental policies and strategies and approves environmental standards. It is assisted by four coordinating councils on the different aspects of the environment including, councils for environmental programs, environmental research and information, environmental education and awareness and sustainable development council.

The Air Pollution Control Rule of 1975 amended in 1994 defines the responsibilities of the Department of Environment regarding air pollution including: the identification of sources of air pollution, determination of acceptable levels of air pollution, inspection and monitoring of operation of industries and businesses, designation of vehicle emission monitoring centers, provision of technical assistance for any privately operated emission monitoring centers and the development of programs to encourage and instruct industries to mitigate air pollution.

Apart from the above organization, some ministries and municipalities also have a department for the environmental aspects. The Ministry of Health has a section dealing with environmental health issues. It has carried out the monitoring of air pollution with a view to measuring its impact on human health. Similarly the Tehran Municipality has a section dealing with environmental matters and is monitoring the air quality in Tehran. The Planning and Budget Organization has an Environment Directorate to provide an additional opportunity to integrate concern for environmental protection and natural resource management into the budget-making process during the preparation of the five-year plans. Finally, The Ministry of Industry, Petroleum and Energy also has a section for environmental research.

For the purpose of protecting the environment, a large number of laws and regulations have been approved. The most significant laws are articles 45 and 50 of Iran's constitution approved in 1979 giving the government wide ranging authority and obligations to protect the environment. Article 50 of the Constitution states that in the Islamic Republic of Iran, protection of the environment, in which the present and future generations must lead an ever-improving community life, is a general obligation. Therefore, all activities, economic or otherwise, which may cause irreversible damage to the environment, are forbidden.

Article 45 of the Constitution further authorizes the government to approve legislation concerning the protection and utilization of natural resources, such as seas, lakes, rivers, other public bodies of water, mountains, rangelands, and soil, which are regarded as national and public properties.

Moreover, according to the Municipality Law of 1965 amended in 1973, the Municipality is responsible for air pollution control within city limits and the relocation of polluting industries to less densely populated areas and to abolish them within the city limits.

1.3.3 Environmental Policy and Strategies

Iran has embarked on a transition to a more market-oriented economic system. The policies to support this goal need to be intricately linked to those for improving the quality of the environment. In this respect, an environmentally and economically sustainable development strategy has become a major objective of the Government's future strategy for the economic transition. Also along with the increase of environmental pollution particularly in large cities, the protection of the environment has become a higher priority.

With regard to the above objectives, Iran has signed major International Environmental Agreements [195] such as: Conventions on Biodiversity[25], Marine Life Conservation[26], Endangered Species[27], Marine Dumping[28], Environmental Modification[29], Wetlands[30], Law of

[25] develop national strategies for the conservation and sustainable use of biological diversity, Iran has not yet ratified.

[26] to solve through international cooperation the problems involved in the conservation of living resources of the high seas, considering that because of the development of modern technology some of these resources are in danger of being overexploited.

[27] to protect certain endangered species from overexploitation by means of a system of import/export permits

[28] to control pollution of the sea by dumping and to encourage regional agreements supplementary to the Convention.

[29] to prohibit the military or other hostile use of environmental modification techniques in order to further world peace and trust among nations, Iran has not yet ratified.

the Sea[31], Desertification[32], Hazardous Wastes[33], Ozone Layer Protection[34] and Climate Change[35].

In spite of the government's struggle to solve the difficulties with the large collection of laws, regulations, and standards governing environmental management, the following problems of environmental and natural resource management in Iran can be identified:

- state ownership of oil and other large energy intensive enterprises with no incentives in terms of energy saving,
- the main source of air pollution in the large cities, i.e. the transport sector remains as before, due to the financial deficit for the replacement of old cars with new,
- lack of economic incentives to reduce pollution and prevent natural resource degradation,
- inadequate resources for monitoring and enforcement of existing standards,
- insufficient emphasis on prevention of problems through prior review of investment proposals and designs.

Reduction strategies that the government aims to carry out are efficient energy pricing, efficiency measures, the expansion of natural gas and transport sector related policies.

- ***Natural Gas Expansion***

The increased use of natural gas in the future expansion of the energy supply will be environmentally beneficial. The increased expansion of natural gas instead of using petroleum products in the residential/commercial, industrial, and electricity sectors can reduce emission in a cost-efficient way. Iran plans to become less dependent on oil domestically by the next century when gas consumption is expected to overtake oil as the primary energy fuel [132].

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[30] to stem the progressive encroachment on and loss of wetlands now and in the future, recognizing the fundamental ecological functions of wetlands and their economic, cultural, scientific, and recreational value.

[31] to set up a comprehensive new legal regime for the sea and oceans; to include rules concerning environmental standards as well as enforcement provisions dealing with pollution of the marine environment.

[32] to combat desertification and mitigate the effects of drought through national action programs that incorporate long-term strategies supported by international cooperation and partnership arrangements.

[33] to reduce transboundary movements of wastes subject to the Convention to a minimum consistent with the environmentally sound and efficient management of such wastes; to minimize the amount and toxicity of wastes generated and ensure their environmentally sound management as closely as possible to the source of generation; and to assist LDCs in environmentally sound management of the hazardous and other wastes they generate.

[34] to protect the ozone layer by controlling emissions of substances that deplete it.

[35] to achieve stabilization of greenhouse gas concentrations in the atmosphere at a low enough level to prevent dangerous anthropogenic interference with the climate system.

Therefore, Iran has succeeded in reducing the domestic oil consumption by increasing the production of natural gas. The oil consumption in Iran dropped by 4.6% to 58 Mt in 1998. As a result of the reduction in oil usage, the consumption of gas rose by 9.9% in 1997.

Iran also aims to promote the use of natural gas as a motor fuel. All taxis in Tehran and provincial centers are now gas-powered, serviced by 50 filling stations which sell LPG and CNG. Another 50,000 private cars run on LPG, and gas kits are to be installed on another 50,000 private vehicles. The construction of another 56 gas filling stations is completed by March 2000.

- ***Energy Conservation***

Energy conservation may be a cheap, quick, and relatively painless way for most developing countries to stretch energy supplies, slash energy costs, and save foreign currency. Experience has shown that technically proven, cost-effective energy conservation and efficiency measures can save developing countries an estimated 10% to 30% of their energy consumption.

There is a large scope for energy conservation in the different sectors in Iran. The Ministry of Energy has identified energy conservation or energy efficiency as a priority measure. The implementation of energy conservation/efficiency measures is expected to be essential for the improvement of air quality in Tehran. For this purpose parliament approved a law to oblige industries with more than five MW energy demand annually to establish an energy management section. Also a new organization (SABA) has been established in charge of conducting energy audits in the various industries. One of SABA’s programs was a training course with the cooperation of ESCAP[36] for energy audits at a cement factory and the reduction of energy consumption. Standardization and labeling are another policy towards energy conservation.

As Table 1-9 shows, the proportion of energy used in Iran to produce one unit of energy is higher than the international standards [236]. The potential of energy savings is particularly high in the basic metals, non-metallic and chemical industries, which consume almost 45% of the total energy consumed in the industries. It is estimated that the overall technical energy conservation potential is as high as 30-50%, although this would require major investments. The other energy saving potential can be found in the refineries which have 6% lost i.e. two times more than advanced technology. Lost during the transportation and distribution of electricity is 13.5% in comparison with 8% in the industrialized countries.

[36] Economic and Social Commission for Asia and the Pacific

A preliminary estimation indicates that the energy savings potential in the residential and commercial sectors is 27-46% and 23-49%, respectively. The main targets for electricity conservation in the residential sector should be lighting, refrigeration and air cooling which consume more than 60% of electricity. About 90% of light bulbs are domestically produced and the ballast consumes 25% of the total energy of the lamp, which is rather inefficient. Therefore efficiency standards should be introduced for domestic products.

Table 1-9: Comparison of Energy Consumed in Iran and Industrialized Countries [236]

Industry	Unit	Modern technology	Available Technology in Iran
Cement	kWh/t	85-110	130-161
Textile	kWh/t	3500-5500	7400-12600
Glass products	kWh/t	70-95	120
Metal products	kWh/t	8-12	30
Primary metal industries	Gcal/t	5.7	9
Chemical products	TOE*/US$1000	0.28	0.71-0.94

*Tons of Oil Equivalent

- ***Pricing***

In an effort to make energy widely accessible to a large number of people, many developing and transition countries use subsidies to keep their energy prices down. However, such subsidies can hinder economic growth and damage the environment. According to the report of the IEA[37], prices for energy consumers in the eight countries including China, India, Indonesia, Iran, Kazakhstan, Russia, South Africa and Venezuela are 20 % below world market prices, ranging from South Africa with 6.4 % to Iran with a huge 80 %. If energy price subsidies are removed in these countries, primary energy consumption would decrease by 14% and CO_2 emissions would decrease by 17% [83].

The calculations of the IEA (see Table 1-10) show that, removing the subsidies could decrease the energy demand, reducing the energy use in Iran by approximately 48% and yielding the additional environmental benefits including greatly lower local air pollution [83].

[37] International Energy Agency

Removing the subsidies might have dropped annual CO_2 emissions by an average of 50% below actual 1997 levels.

Cutting the subsidies could also increase annual GDP by 2.22%. The IEA agency identifies other economic benefits including enhanced energy security, relieving strains on government budgets and revitalizing energy industries.

Table 1-10: The Consequences of Subsidy Removal (1997) [83]

Country or Region	Average Subsidization (% of reference price)	Annual Economic Efficiency Gains (% of GDP)	Reduction in Energy Consumption %	Reduction in CO_2 Emissions %
China	10.89	0.37	9.41	13.44
Russia	32.52	1.54	18.03	17.10
India	14.17	0.34	7.18	14.15
Indonesia	27.51	0.24	7.09	10.97
Iran	**80.42**	**2.22**	**47.54**	**49.45**
South Africa	6.41	0.10	6.35	8.11
Venezuela	57.57	1.17	24.94	26.07
Kazakhstan	18.23	0.98	19.22	22.76
Total Sample	21.12	0.73	12.80	15.96
% of Non OECD	N.a.	N.a.	7.48	10.21
% of World	N.a.	N.a.	3.5	4.59

Most energy resources are substantially under-priced relative to the opportunity costs in Iran. The low price of oil-products is one of the important reasons for the increasing domestic consumption. The average price of oil-products in the country is approximately 5% of its international equivalent. Among the energy consumption patterns, the government prefers the gradual reduction of subsidies. Raising energy prices would induce the consumers of energy in all sectors to conserve and increase the efficiency of energy. Therefore the government implemented the policy of gradual price increases as it had the least social impact. Due to the high inflation rate compared to the price growth rate of energy, which remained fixed in the family consumption, domestic consumption has not changed efficiently.

Similarly, there are large subsidies in the electricity sector. The real production cost for one kWh was 160 Rials whereas the sale price was half of that in 1997. Hence there was also no incentive to purchase more efficient electrical equipment. The use of more efficient equipment would become economical if the electricity prices are raised. The government is getting ready to take measures to reduce subsidies on the electricity sector within the application of a price liberation policy.

Iran has become increasingly dependent on the imports of gasoline to meet the rapid demand growth. The consumption of gasoline is too high because of heavy state price subsidies and widespread smuggling in the border provinces. Consequently, at current gasoline prices vehicle owners have no incentives in terms of fuel savings to tune their vehicles regularly. The government aims to reduce the subsidies, but high inflation is also an obstacle to reaching the real energy price [174].

- ***Tehran's Environmental Policies***

In order to find a solution for the air pollution and relevant projects in Tehran, the city's municipality has established the Air Quality Control Company (AQCC) in 1993. The overall objective of projects done by this company is the formulation of a comprehensive medium and long-term plan for the achievement of acceptable levels of air pollution. Some of them have been implemented in collaboration with international organizations (the Japanese International Co-operation Agency, the World Bank and the Lausanne Ecole Polytechnique).

These projects include the installation of air pollution measuring stations and the measurement of pollutants in three urban terminals, gathering pollution data pertaining to metallic and non-metallic elements, applying visual processing for air pollution control, organizing a census of motorcycles on the city routes and supervising the use of fuel by the taxis of Tehran, investigation of the effects of the improvement kit installed on the Paykan[38] motor, annual testing of each car, expansion of remote-sensing traffic system, prevention of gasoline overflows from car tanks as well as reorganizing industrial projects in the west of Tehran.

An evaluation of the effects of a comprehensive education and training plan to increase public awareness concerning air pollution, a study of the effects of regulating motors to curb pollution caused by gases emanating from exhausts of motorcycles, prevention of gasoline overflows from car tanks, and many other schemes are likewise being planned by the AQCC.

Another plan to control pollution in Tehran also has been carried out by the Japan International Cooperation Agency (JICA) and AQCC in the period 1995-96. This plan had two main objectives, the creation and institutionalization of a comprehensive plan for air

[38] The name of the most produced and used in country car.

pollution and the transfer of a suitable technology. This project was divided into three stages. The first part of the plan involved initial research, collection of available meteorological and air pollution information as well as investigation of economic and social conditions. The second stage entailed the measurement and analysis of studies made in the first phase, development of a simulation model of air pollution and forecasting future situations. The last phase was the drawing up of a comprehensive plan to combat air pollution.

The methods announced by the JICA for decreasing and controlling pollution were the reduction of sulphur in fuel, better fuel quality, improving traffic mobility and control of gas emissions from the car exhausts. All these have already been enforced by organizations in charge of pollution control in the city.

The other project, namely, an integrated master plan for air pollution control in Tehran has been implemented with the collaboration of the Tehran Municipality and the Global Environment Facility (GEF). The functions and responsibilities of all organizations and ministries for pollution control have been specified in the master plan. With the execution of a comprehensive action plan to improve the air pollution in Tehran, the pollution density would decrease by 16% in the capital city. The plan would take 10-15 years to be carried out, adding that it would solve the air pollution problem systematically. The objectives pursued by the plan were, observing the standards of the pollutants, changing car fuel to gas, use of a catalytic converter in new cars and the withdrawal of old cars, increasing the number of public transportation gas vehicles, improving fuel quality, technical inspection of vehicles and public training to avoid adding to the air pollution.

The Environment Protection Organization of Iran aims to compile the standards and regulations to facilitate the control of air pollution in the country. The organization is making a quantitative and qualitative analysis of air pollution as a preamble to offer methods to control the various kinds of pollutions.

2 Methods and Tools for Environmental Assessment

2.1 A Review of Energy-Environment Models

The energy and environmental planning as an instrument for decision making have been more important in a world facing increasing environmental degradation, due to the increase in energy consumption. Energy-related problems continue to be a major obstacle to economic growth in most developing countries, where energy investments form a large proportion of total public investment. Major funds are necessary to achieve the challenging environmental targets and to provide sufficient energy with a reliable supply system for a growing population in an environmentally sustainable way. The complexity of energy and environment can be characterized by many interactions between energy, economy, and environment.

The background of energy planning studies returns to the first oil shock in the 70's that revealed the importance of fuel substitution. The goal of studies moved toward finding an optimal fuel mix for the energy supply system. This made it necessary to evaluate the potential of all available resources, whereas the feasibility of new energy technology planning tools in the past concentrated frequently on specific modeling issues. Their methodology often focused only on one aspect of the problem such as costs, environmental damage, or energy supply security. Usually only one economic sector such as the household sector or industry was analyzed or only one energy carrier such as electricity was considered. The technology oriented "process-engineering" model generation initially focused on single fuel issues or energy sub-sectors, such as the electricity generation planning models in the sixties [14].

The first energy models were written based on econometric theories and correlated energy demand with macro-economic indicators like the GNP [216]. The models were created using procedural languages and concentrated on the mathematical algorithms of the model, and information was arranged according to the procedural flow of the incorporated algorithm. The integrated nature of energy issues and the interactions with the economy and the environment became widespread during the seventies. The complexity of models has been greatly influenced by development in the information technology.

The former models were not suitable for the growing challenges of the complex planning tasks. Beside the incompetent structure of these models, impact on the environment due to the expanding use of energy during the 70's was underestimated. New planning tools were required to integrate energy, economy, and environment issues in one framework. The assessment of the environmental impact of energy system became more important and lead to a conflict situation of low-cost energy supplies and environmental protection. Current modeling activities aim at the development and transfer of the models which are suitable for solving problems with due attention to needs on international, national and regional levels. Several models have been developed and used in recent years for planning, mostly on a national level. They vary from econometric models to techno-economic models that analyze sectoral energy consumption on a detailed level.

There are many ways of characterizing the different models, while there are only few models that fit into one distinct category. These ways can be include [27]: general and specific purpose of energy models, the model structure (internal and external assumption), the analytical approach (top-down vs. bottom-up), the methodology, the mathematical approach, geographical coverage (international, regional, national), sectoral coverage, the time horizon and data requirement. Figure 2-1 shows the energy-environmental tools, which are classified within the five categories.

The energy models are usually developed to reply specific questions and suitable for the purpose they were designed for. The models can be classified by purposes such as: energy demand, energy supply, impacts, appraisal, integrated approach and modular build-up [27]. The most common purposes are:

1. Energy Demand Models

Energy demand models are built to study the sectoral energy demand and its growth on final energy and useful energy. Among the energy demand models, the engineering-process method is widespread, but econometric models are used as well [162]. Important demand tools are MEDEE[39], and MAED[40].

2. Energy Supply Models

The energy supply models are concerned with the minimization of the cost of achievement given an increase in the energy supply, subject to a number of constraints. These include technological, financial and environmental constraints. They take the demand as given and do not investigate the impacts of using prices and other instruments of energy demand management to bring demand and supply into balance. The models generally use simulation or optimization methods. The latter method is usually based on linear and non-linear programming. EFOM, MARKAL, and MESSAGE are tools concerned with optimization methods.

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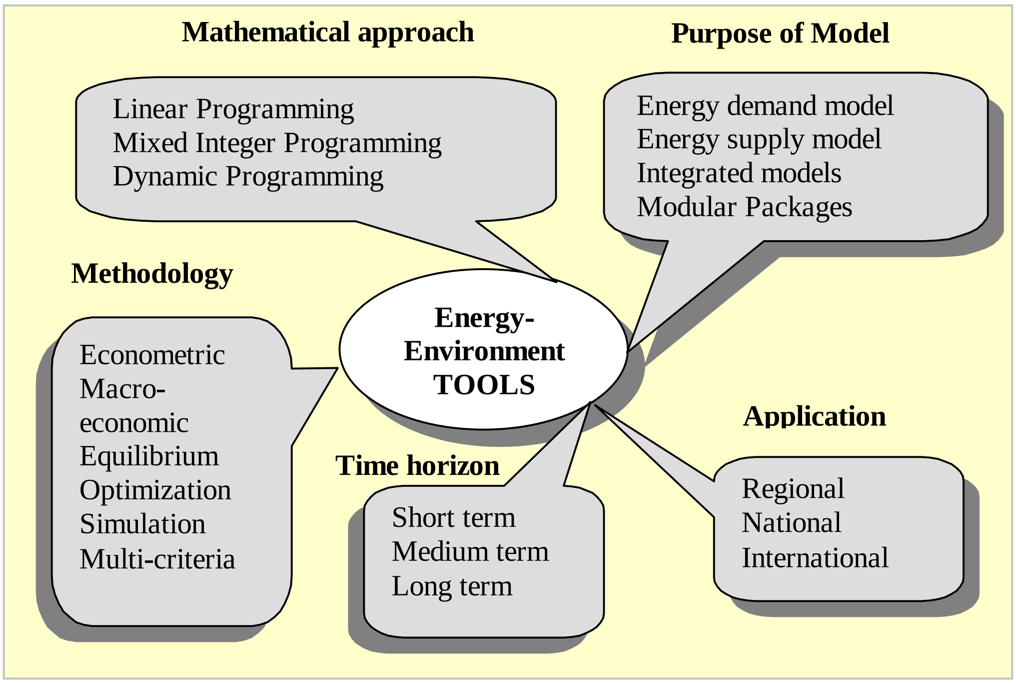
[39] See page 61
[40] See page 61

Figure 2-1: The Structure of Energy-environmental Tools[41]



3. Modular Packages

These tools consist of several different kinds of models such as a macro-economic component, an energy supply and demand balance, an energy demand alone, etc which are integrated into a package. The user does not need to run all the models but may select only a subset depending upon the nature of the analysis to be carried out. Some of the well-known tools are ENEP[42], LEAP[43], and MESAP[44] [82].

A general overview of the most important models is described as follows:

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[41] - General equilibrium analysis (Equilibrium method): An approach which considers simultaneously all the markets in an economy, allowing for feedback effects between individual markets. It is particularly concerned with the conditions which permit simultaneous equilibrium in all markets, and with the determinants and properties of such an economy-wide set of equilibrium [183].
- Econometric model: An econometric model is a probabilistic model consisting of a system of one or more equations that describe the relationship among a number of economic and time series variables.
- Simulation model: Descriptive model based on a logical representation of a system, and aimed at reproducing a simplified operation of this system. A simulation model is referred to as static if it represents the operation of the system in a single time period; it is referred to as dynamic if the output of the current period is affected by evolution or expansion compared with previous periods. The importance of these models derives from the impossibility or excessive cost of conducting experiments of the system itself [194].

[42] See page 63
[43] See page 61
[44] See page 62

- ***MEDEE***

The MEDEE model (Model for Demand of Energy for Europe) is a techno-economic model for the forecast of final energy demand. For five considered sectors (industry, transport, households, services and agriculture) the demand for various types of energy is forecasted for each sector for a base year and various years in the future [212].

- ***MAED***

The Model for Analysis of Energy Demand (MAED) is a simulation model designed to evaluate medium- and long-term demand for energy in a country or region. The model was developed by the International Atomic Energy Agency (IAEA) and was originally based on work done at the University of Grenoble in France. MAED offers an alternative approach to MACRO/DEMAND/BALANCE for estimating energy demand and electricity demand. The MAED model consists of three modules: an energy demand module that calculates the final energy demand per energy form and per economic sector for each reference year according to the various parameters describing each socio-economic and technical development (e.g. energy efficiency) scenario, an hourly electric power demand module converts the total annual demand for electricity in each sector to the hourly demand and a load duration curve module ranks the hourly demands imposed on the grid in decreasing order of magnitude and provides the load duration curve. The output of the MAED model consists of detailed estimates of alternative energy forms used in each sub-sector for each selected year.

- ***LEAP***

LEAP, the Long-range Energy Alternatives Planning system, is a tool for energy-environment planning and greenhouse gas mitigation analysis. It has been developed by the Stockholm Environment Institute - Boston and uses a simulation approach to represent the current energy situation for a given area and to develop forecasts for the future under certain assumptions. LEAP is very appropriate for wood energy planning because it contains a land use module that can be used to assess available wood resources [185].

- ***MESSAGE***

The Model for Energy Supply Systems Analysis and their General Environmental Impact (MESSAGE) developed by the International Institute for Applied Systems Analysis (IIASA) is a demand driven quasi LP model, which is generally used for the optimization of energy supply systems. The model minimize the discounted costs of supplying energy subject to a given level of final energy demand and assumptions on costs, efficiencies and market penetration constraints. In the developed MESSAGE, the investment costs of specific technologies are linked to the cumulative installed capacity using learning curves. The costs of specific energy technologies decrease as commercial investments and installed capacities accumulate. MESSAGE evaluates also energy systems costs and capital requirements for energy planning and the impact of CO_2 tax on the energy mix ([5][177] [114]).

- ***MESAP***

MESAP (Modular Energy System Analysis and Planning Software) is a decision support system for integrated energy Management developed by the IER (Institut für Energiewirtschaft und Rationelle Energieanwendung). It offers tools for investment calculation, energy and environmental accounting, demand analysis, integrated resource planning, demand-side management, as well as electricity operation and expansion planning, life cycle and fuel chain analysis. The three layers of the MESAP architecture are the database tools, models and central information systems. The database management system at the core of MESAP consists of NetWork. MESAP includes the models PlaNet for demand analysis and supply simulation, INCA for investment calculation and financial analysis, E3-Net for energy system optimization (LP) and PROFAKO for electricity and district heat operation and expansion planning. All planning models connected to NetWork use the same data entry and analysis tools and can exchange input data, assumptions, and results. On the level of the central information systems MESAP includes ENIS (the ENergy Information System) a link to geographical information systems, and a link to the IKARUS technology database [216].

- ***RAINS***

The RAINS model was developed at IIASA for the integrated assessment of alternative strategies to reduce regional SO_2 and NO_x and VOC emissions to below a ‘critical load’, which refers to the environmental impacts of the deposition, originally designed for application in Europe [7]. The model has been further developed for Asia. The RAINS model uses data , stored in dBase format, regarding energy scenarios, emission control technologies and abatement costs, atmospheric transport and critical loads. RAINS allows the user to examine the costs and effectiveness of the different emission control strategies under various energy-use scenarios .

- ***POLES***

The POLES (Prospect Outlook on Long-term Energy Systems) model is a simulation model providing long-term energy supply and demand scenarios on the basis of hierarchical systems of interconnected sub-models on an international and regional level [79]. On the basis of energy consumption scenarios, future GHG emissions can be analyzed in order to identify strategic areas of action and to define appropriate technological change and R&D strategies. Furthermore, the impacts of the emission reduction strategies on the international energy markets can be assessed. A detailed description of the oil, coal and gas market on a world level allows a significant increase in the size and complexity of the model.

- ***MARKAL-MACRO***

The MARKAL-MACRO model was developed by Brookhaven National Laboratory (BNL) to support strategic energy planning ([3][29][59]). It links MARKAL (Market Allocation) and MACRO to analyze the energy, environmental and economic factors. MARCAL is a technologically oriented dynamic linear programming model of the energy sector. In the coupled MARKAL-MACRO version, energy service demands are determined by macroeconomic activity and by conservation. The energy-economy linkage is established through the physical flows of energy from the MARKL into the MACRO and energy cost payments from the MACRO into the MARKL. The MARKAL portion of the model addresses the role of energy, natural resources, transportation, processing of energy sources, and other production/consumption factors. The outputs of the model consist of optimal mixes of fuels and technologies, emission sources and levels for various strategies, marginal cost for various technologies and applications, and specific points such as the value of carbon rights (marginal cost of emission). MARKAL is used in the European countries, North and South America, Africa and Asia. In the United States, the MARKAL-MACRO has been selected to support the Global Climate Change Initiative agreed to under the Framework Convention on Climate Change in 1992.

- ***ENPEP***

The Energy and Power Evaluation Program (ENPEP) model has been created by Argonne National Laboratory [32]. ENPEP integrates the evaluation of alternatives for expanding electrical generating systems over a 30 year planning horizon with information about overall economic growth, availabilities and relative costs of competing sources, and environmental impacts of alternative supply systems. ENPEP is a modular system consisting of nine parts so that each module deals with a specific aspect of the energy and power evaluation process.

Users are given wide latitude to vary parameter values and select the specific activities, fuel types, and technologies represented by each module.

2.2 The EFOM-ENV[45] Model

The Energy Flow Optimization Model (EFOM) had been developed as an energy supply optimisation model by the European Union [58]. It was initially developed in 1970 at the "Insititut Economique et Juridque de l'Energie" (IEJE) in Grenoble, France. The model aimed to elaborate the strategies making west Europe more independent of oil imports and to determine those technologies for reaching the goal. Its structure was based on linear programming with a minimization of the total discount costs in order to meet the energy requirements of a country or region over a long period by considering different objectives. The model philosophy was based on the identification of interrelationship between different sectors of energy system and economic activities necessary to meet future energy demands for a given country or region. The main characteristics of the first version of EFOM model were:

- on the basis of given demand for useful or final energy, the optimal supply structure for all kinds of fuels is calculated.
- the modular structure allows for sectoral optimization (e.g. capacity extension planning in the central utility sector). These modules can be subdivided into primary energy extraction, import and preparation sectors, conversion, and utilization sectors.
- energy conversion and transport technologies are modeled by technical and economic data, such as: fuels, efficiency, capacity, investment, fixed and variable costs, technical availability and lifetime.

With the growth of energy consumption and the appearance of environmental difficulties especially acid rains, the European Union tried to find solutions for them and select strategies and technologies for reducing the emission of pollutants especially for SO_2 and NO_x [108]. Since the EFOM model considered only the energy problem, it was not able to solve the environmental complexities. Therefore a new model has been developed with so-called 'environmental modules'. The extended version done by the IIP[46] is named EFOM-ENV. The primary EFOM-ENV model was programmed in Fortran, later in 1985 in order to ease modelling and to improve portability to other platforms, the Netherlands Energy Research Foundation translated it to GAMS[47] to build their energy models for scenario development and policy analysis [31].

[45] Energy Flow and Optimization Model - Environment
[46] Institute for Industrial Production, University of Karlsruhe
[47]General Algebraic Modelling System

This energy-environmental model will be able to reply the following questions:

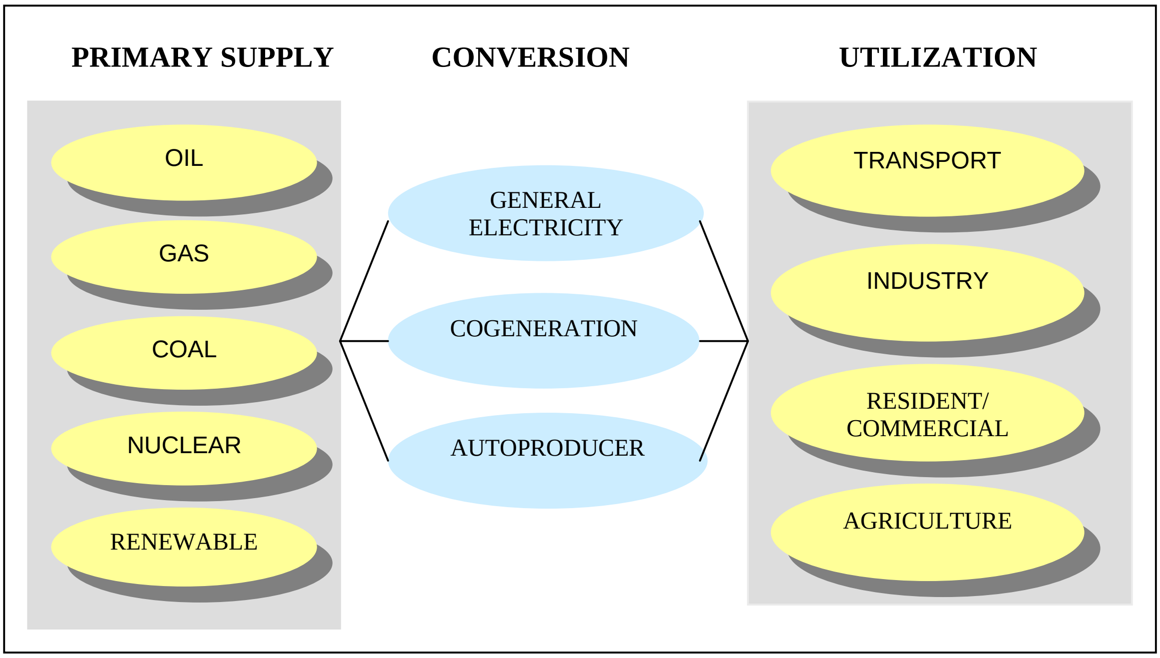
- How should an energy system be developed in order to assure a safe and cost efficient energy supply?
- What development of emissions can be expressed when no new environmental legislation is being enforced?
- What kind of measures have to be implemented in order to meet the environmental goals and what are the impacts on structure, energy supply and emission reduction costs?
- How do strategies and related costs depend on underlying assumptions (energy price, development of economy and energy demand,…)?

To obtain a proper answer to the above mentioned questions, it was necessary to distinguish between two different approaches for analyzing the energy supply structure and to determine possible future developments for the primary energy consumption and emission level: A simulation or an optimization mode. Using a simulating operation mode, questions such as “If ... ,then ...?” can be answered. To determine the useful energy demand, the resource and technology mix have to be identified. On the other hand, using an optimizing operation mode for questions such as “What ..., if ...?” the energy demand and the emission level have to be given. The result provided the optimal resource and technology mix for chosen optimization criterion, which has to be defined exogenously, e.g. cost effectiveness, etc [37].

For the determination of an inter-temporal optimal allocation of emission reduction technologies and energy conversion units, the optimizing model is considered to be the most appropriate. Consequently, an optimal linkage between emission reduction and energy conversion units is obtained. Using several criteria, results help to analyze air pollution control strategies by modifying the range of developments over a period of time. Therefore, projections of possible future developments can be determined, e.g. developments of optimal primary energy consumption, technology mix and emission levels. The forecast of the final or the useful energy demand is not the target of the application. In large-scale studies, the actual existing energy conversion units and resources are aggregated to a high extent. To consider the conflict between energy conversion and emission reduction, the types of energy conversion units must be adequately linked with the emission reduction measures/technologies.

EFOM-ENV is a process oriented description of energy systems. The model is based on identifying the set of energy chains and economic activities associated with satisfying the energy demand. As Figure 2-2 shows, the structure of the model consists of three major subsystem components: extraction or the primary energy supply systems, transformation or the energy conversion systems and the energy consumption or the energy final demand systems [214]. The energy system is described by an energy flow through a network starting with the representation of individual primary energy resources, going on to the various energy conversion processes up to the final/useful energy demand. All flows entering the energy system are called resource flows. These flows represent imports or extraction of energy carriers such as oil or wind. The second group receives the energy carrier and after converting it, delivers to the demand sector. In the demand sector, such as the industry or transport sectors, energy will be consumed.

Figure 2-2: Structure of the EFOM-ENV Model

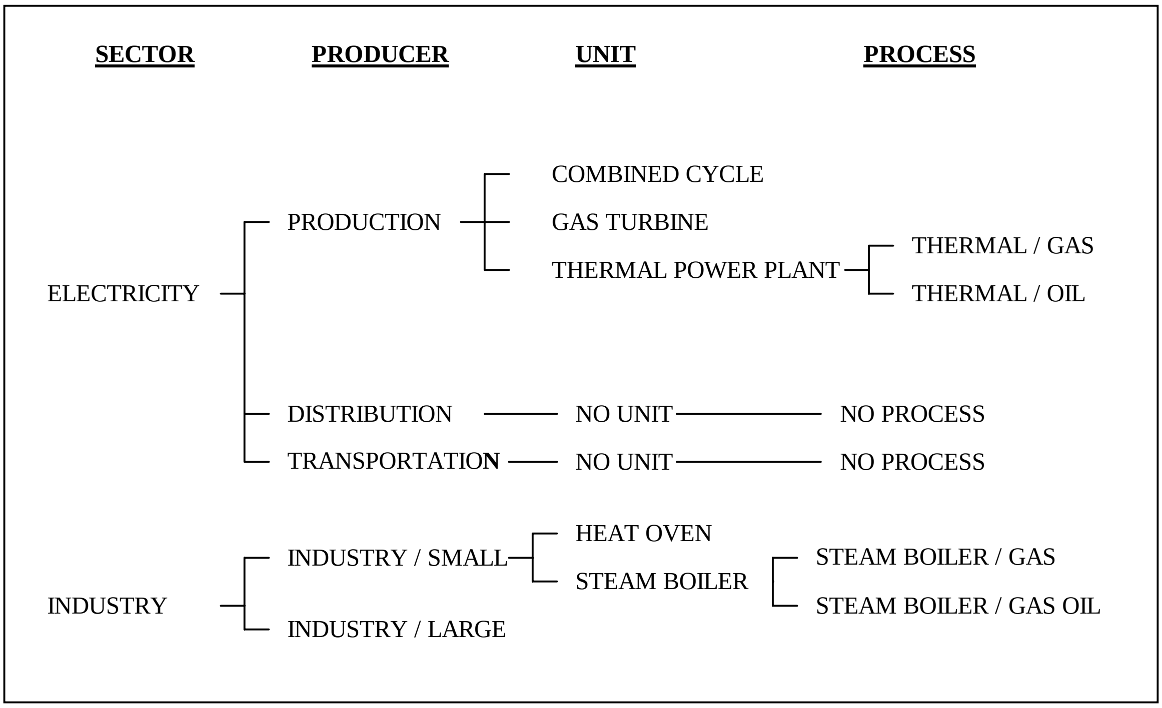


As shown in Figure 2-3, the energy processes are aggregated at four hierarchical levels: sectors, producers, units, and processes. The energy system for a country is specific to different sectors such as oil, gas, electricity, transport and industry to generate the energy balance, cost, and emissions for each. Sectoral specifications may vary in each country, as the energy system structure may have a stronger weight on the other sectors, for instance on the agriculture sector [214].

A producer represents an organization, which has a special function in the energy system. All producers receive, convert, and deliver energy carriers. For example the procedure for oil is extraction, refining and distribution. There are two categories of producers, namely the resource category and the demand category. The resource indicates where energy carriers enter the system, at importing, extraction, or renewable sources. The demand category shows the places where the useful/final energy is needed.

The other level or unit, is a real physical capacity of a special energy conversion technology, for example a gas turbine or combined cycle power plant. A process is the most disaggregated level of an energy conversion and characterized by a specific energy carrier input and output and by the process parameter. At this level differentiation is made regarding the type of fuel input or emission performance.

Figure 2-3: Hierarchical Structure of the EFOM-ENV Model

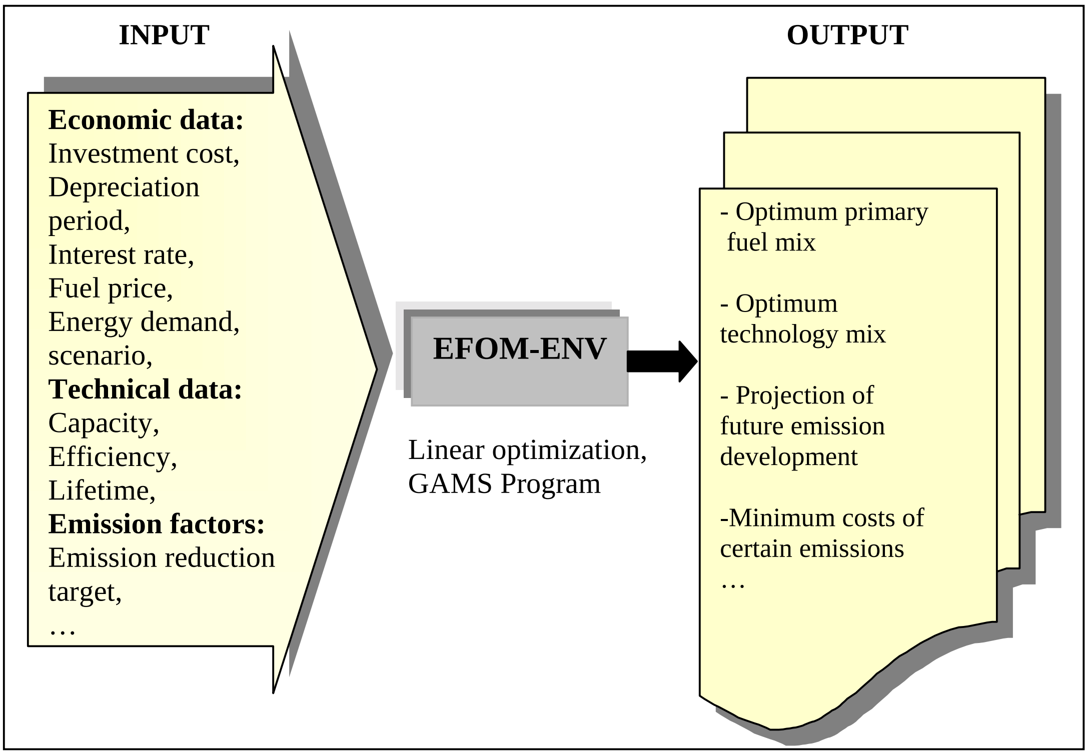


Energy conversion technologies are characterized by input and output fuels, efficiency, existing capacity and required investment for additional capacity, fixed and variable costs as well as technical annual availability and lifetime and emission factors depending on the input fuel. As indicated in Figure 2-4, each of above mentioned systems requires technical characteristics (conversion efficiencies, installed capacities, by-products, etc.) as well as economic (investments, fixed and operating costs) and emission related properties (e.g. emission factors for several substances) that will be considered in the optimization objective function. Through definition of different scenarios the model examines various hypotheses.

Then by ‘what if’ analyzing the results, the emission control strategies can be compared considering their emission reduction capabilities and their impact on the structure and economy of the energy system.

The technological minimum cost function is obtained for each type of energy conversion and emission reduction technology in the model. The various energy supply structures of different countries together with technological functions make it possible to elaborate country-specific cost functions as a result of an optimal technical and economical assessment analysis.

Figure 2-4: Structure Data of the EFOM-ENV Model



In the EFOM-ENV model, the emission reduction technologies are represented on an adequate aggregation level. These technologies were selected under technical, environmental, economic, and political aspects from a great variety of possible measures. These technologies must be modeled in the same way as the corresponding energy conversion technologies. In addition, the model must be able to deal with different environmental policies, for example, emission standards (e.g. 200 mg NO_x/m^3 flue gas), fuel specifications (e.g. 0.3% sulphur content of gas-oil) and fuel and technology related emission factors. These capabilities permit the investigation of different reduction measures as well as the evaluation of their effectiveness. The reduction measures, which can be assessed with the model, can be grouped together according to the following characteristics:

- Fuel switching and improvement of fuel quality

designates the substitution of high-emission fuels by 'clean' fuels in combustion installations, where several fuels can be used. An example of fuel switching measures is the substitution of fuel oil by natural gas in the oil/gas power plants.

- Substitution of energy conversion techniques,

includes the substitution of high emission energy conversion processes by low-emission ones, for example the substitution of coal power plants by gas-fired power plants.

- Energy conservation measures,

include all technical and economical measures aimed to reduce the specific energy demand of a production system or energy sector.

- Emission reduction technologies,

consist of different technologies which have been developed to reduce air pollution. They depend on the type of fuel and the technologies vary. For instance, wet limestone and dry sorbent injection are available to decrease SO_2 emissions.

Moreover, these measures can be combined to form numerous mixed strategies in order to achieve pre-defined standards or general emission levels. All specific emission reduction technologies are grouped together in the environmental modules and linked to the corresponding energy module. This approach makes it possible to consider pollutants on different aggregation levels. Another advantage of this concept is the impact analysis of environmental legislation. National policies as well as the impact of different emission standards can be evaluated. In addition, the restructuring of energy systems as a possible consequence of a tightening of environmental policies can be studied.

The model has been used for several international studies such as 'Energy and Environment, Methodology for Assessment of Acid Air Pollution in Europe ([13][66][67][100]) 'and 'Cost-effectiveness analysis of CO_2 reduction options' [35] as well as for various studies on a UN-ECE[48] level. The model is available for all Member States of the European Union as well as for Bulgaria, the Czech Republic, Hungary, Latvia, Lithuania, Poland, Romania, Russia, Slovenia, Slovakia, Turkey, Ukraine and also the non-European countries such as Indonesia, Mexico and the Dominican Republic ([68][92][134]).

The EFOM-ENV model written with the GAMS language is compatible with the UNIX and MS-DOS operating system. The required workplace and time depend on the level of aggregation, the specification of optimizing and the number of periods.

2.2.1 Development of the EFOM-ENV Model to PERSEUS[49]

New requirements in relation to energy and environment caused the IIP to improve the model and to develop it to the different modules and models on the basis of EFOM-ENV. They have been presented in a package called PERSEUS, which besides the traditional EFOM-ENV model, includes improvements and new models for optimizing energy systems and developing emission reduction strategies for countries in transition, small countries and for the energy supply companies [57]. Figure 2-5 shows these tools, which are all programmed in GAMS and can be combined according to the requirements of a specific application.

- ***Fuzzy Model***

The Fuzzy model has been developed to solve some restrictions in the energy-environmental model such as limits on emission or parameters like costs or efficiencies with an uncertainty nature ([124][106]). In this model, fuzzy sets are used to characterize the uncertainty about future developments of exogenously given technological and economic parameters (e.g. of energy demand) as well as the degree of satisfaction of a decision maker.

- ***Partial Equilibrium Model***

The term partial equilibrium model is used for models, that place the energy demand as a dependent variable of the price of energy, which itself is modeled in system [162]. The primary EFOM-ENV model is determined by an exogenously given energy demand, therefore change in useful energy demand due to the increasing of prices (e.g. as a result of implementation of expensive CO_2 emission reduction measures) cannot be modeled. This

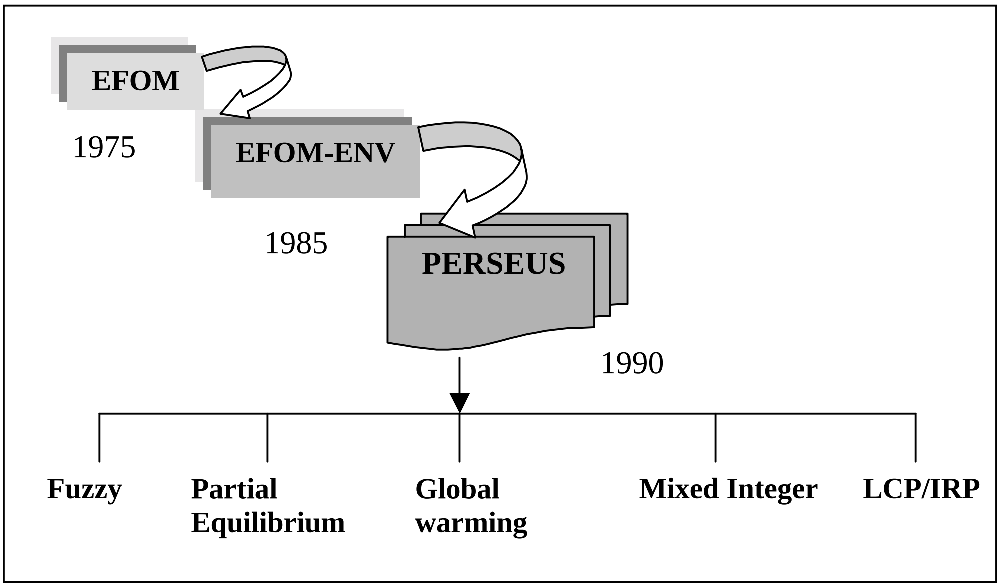
[48] United Nations – Economic Commission for Europe
[49] Program (Package) for Emission Reduction Strategies for Energy Use and Supply

model uses estimations on price elasticities and a modified Cobweb Algorithm to estimate the feedback between energy prices and energy demand ([218][106]).

• ***Global Warming Model***

The other version of the EFOM-ENV model, namely the global warming model, is used for the reduction of major emissions of greenhouse gases (GHGs). In this model, strategies can be developed for achieving a given emission reduction ceiling as well as an effect reduction ceiling for a given year or period. Two methods can be considered to elaborate the various impacts of different gases on the climate change. The first approach uses Global Warming Factors representing the duration and the effect of GHGs inside the atmosphere within one single figure. Through the second approach, these two aspects are considered individually in the model and the actual amount of gas still in the atmosphere is considered ([16][17][56]).

Figure 2-5: The Development of the EFOM Model



• ***Mixed Integer Model***

In the linear optimization model the capacities of a specific technology are considered as a continuous variable. A new model has been developed on the basis of integer variables, which is defined for the most important technologies representing the number of units of a fixed capacity and related size-specific parameters. The economic effects like the economies of scale can be considered as well as technical aspects, such as the impossibility of change in capacity of an existing plant by any small quantity. This model is designed for use in small countries and for analyses, which require the consideration of single conversion processes or single emission sources respectively also in the optimization process [105] [107].

- ***LCP/IRP Model***

Least Cost Planning (LCP) or Integrated resource planning (IRP) has been developed for electric and gas utility planning for future energy requirements. Whereas traditional planning for the energy sector primarily focused on the energy supply, IRP aims at providing energy services to society at the lowest possible costs and with the least negative impacts. The model uses a multi-period mixed integer linear programming technique. This approach and possibility of a more detailed representation of an energy system is also a requirement for application on the level of energy supply companies. A variety of further modifications has been made to represent the situation of energy utilities like maximizing benefits, better disaggregation of load curves, restrictions on investments and detailed descriptions of energy delivery contracts ([178][158][161][180]).

2.2.2 Principle of the Mathematical Formulation

The EFOM-ENV model belongs to the category of quasi-dynamic linear optimization models. The objective of the model is to minimize the total discounted costs for energy supply and emission reduction for a given energy demand over a time period (usually 20 years). With the change of different constraints and comparing the system costs with a reference case, cost functions representing total costs for achieving a specified ceiling can be derived. The model optimizes the capacities and production levels of energy conversion and emission reduction processes and the energy flows with in the network. The model contains a set of linear equations. They can be categorized in different groups of equations: balance equations, capacity equations, market allocation equations, abatement equations, investment constraints ([121][214]).

- ***Objective Function***

The objective function is the minimization of the total discounted costs of the energy system over the entire planning period. Costs can be defined for the purchase/mining, transport and conversion of energy flows.

$$tot\cos t = \sum_t discfac_t \times (\text{Resource}Costs_t + DistributionCosts_t + DemandCosts_t + \text{Process}Costs_t + FixedCosts_t + InvestmentCosts_t + AbatementCosts_t)$$

$$discfac_t = \sum_j^{year_t} (1+discrate)^{-j-\sum_b^{b<t} year_b} \qquad j = \textit{Number of years in period t}$$

$$\sum_e \sum_i \sum_n \text{R}_{e,i,n,t} \times (purpric_{e,i,n,t} + \text{costvar}_{e,i,n,t}) \qquad \textit{Resource Costs}$$

$$\sum_e \sum_{n'} \sum_n (I_{e,n',n,t} \times \text{costvar}_{e,n',n,t}) \qquad \textit{Distribution Costs}$$

$$\sum_e \sum_n \sum_d D_{e,n,d,t} \times (\text{costvar}_{e,n,d,t} - selpric_{e,n,d,t}) \qquad \textit{Demand Costs}$$

$$\sum_p (P_{p,t} \times \text{costvar}_p) \qquad \textit{Process Costs}$$

$$\sum_u (capac_{u,t} \times \text{costfix}_u) \qquad \textit{Fixed Costs}$$

$$\sum_u anfac_u \times (\sum_b \min(Rl_{u,b,t}, year_t) \times BUI_{u,b}) \times \text{costinv}_u / year_t \qquad \textit{Investment Costs}$$

$$anfac_u = \frac{irate}{1-(1+irate)^{-lifetec_u}}$$

$$\sum_a \sum_p (abat_{a,p,t} \times \text{costabat}_{a,p}) \qquad \textit{Abatement Costs}$$

$$\text{costabat}_{a,p} = \frac{irate \times \text{costinv}_{a,p} \times convabat}{(1-(1+irate)^{-lifetec_a}) \times avaifac_{a,p}}$$

- ***Balance Equations***

All the balance equations specify that the energy entering the energy system equals the consumed energy plus the energy losses in the system. Thus the sum of energy flows entering the producer is equal to the sum of energy flows leaving the producer, except for the transformation losses. The balance equations are divided into three groups: general balance equations, special balance equations to model the load duration curve and a balance equation to model the storage of energy.

$$\sum_i R_{e,i,n,t} + \sum_{n'} I_{e,n',n,t} + \sum_{p_n} (P_{p_n,t} \times Y_{e,p_n}) = \sum_{n'} I_{e,n,n',t} + \sum_d D_{e,n,d,t}$$

$$\sum_i R_{e,i,n_e,t,seas} + \sum_{n'_e} I_{e,n'_e,n_e,t,seas} + \sum_{p_{n_e}} (F_{p_{n_e},seas} \times P_{p_{n_e},t} \times Y_{e,p_{n_e}}) = \sum_{n'_e} I_{e,n_e,n'_e,t,seas} + \sum_d F_{e,n_e,d,seas} \times D_{e,n_e,d,t}$$

$$F_{seas} = \frac{D_{seas}}{D_a}$$

$$\sum_{p_{n_e}} (P_{p_{n_e},t,peak} \times Y_{e_e,p_{n_e}}) = \sum_{n'_e} I_{e_e,n_e,n'_e,t,peak}$$

$$\sum_{p_{n_e}} (P_{p_{n_e},t,base} \times Y_{e,p_{n_e}}) = \sum_{n'_e} I_{e_e,n_e,n'_e,t,base}$$

$$\sum_{i} R_{e_e,i,n_e,t} + \sum_{n'} \mathrm{I}_{e_e,n_e,n'_e,t} + \sum_{seas} \sum_{p_{n_e}} (P_{p_{n_e},t,s} \times Y_{e_e,p_{n_e}}) = 0$$

$$\sum_{n'_e} I_{e_e,n'_e,n_{e_{st}},t,base} + (P_{p_{n_{e_{st}}},t} \times Y_{e_e,p_{n_{e_{st}}}}) = \sum_{n'_e} \mathrm{I}_{e_e,n_{e_{st}},n'_e,t,peak}$$

- ***Capacity Equation***

The necessary installed capacities and the additional capacities that have to be built in each period are determined by the capacity equations. Capacities are determined for each unit for which investment costs or fixed costs are given. The unit capacity equation states that the installed capacity for a unit is sufficient to produce a certain output taking into account the availability of the capacity. The conversion factor makes it possible for capacities to be expressed in different units like MW or PJ/Y.

$$CAPAC_{u,t} = RESC_{u,t} + \sum_{b<t} MIN(Rl_{u,b,t} / year_t, 1) \times BUI_{u,b}$$

$$CAPAC_{u,t} \times Avaifac_u \times Convfac_u \geq \sum_{p_u} P_{p_u,t} \times Outelec_{p_u}$$

- ***Market Allocation Equation***

Market allocation equations are used to model shares of energy technologies on the market in the cases when cost optimization will give an unrealistic result. There are two kinds of market allocations. The market allocation equations are for a process describing the constraints on the ratio between a process level and its unit level. The unit level is the sum of process levels belonging to that unit. The market allocation equations are for a unit describing the constraints on the ratio between a unit level and its producer level. The producer level is the sum of the unit levels belonging to that producer.

The following equations determine the exact ratio between the different levels or put constraints on this ratio:

$$Y_{e,p,t} \times P_{p,t} = Mal_{e,p,t} \times \sum_{p_u} (Y_{e,p_u} \times P_{p_u,t})$$ *Market allocation equations for a process (u,p,t)*

$$Y_{e,p,t} \times P_{p,t} \geq Amin_{e,p,t} \times \sum_{p_u} (Y_{e,p_u} \times P_{p_u,t})$$

$$Y_{e,p,t} \times P_{p,t} \leq \mathrm{Amax}_{e,p,t} \times \sum_{p_u} (Y_{e,p_u} \times P_{p_u,t})$$

$$\sum_{p_u} (Y_{e,p_u} \times P_{p_u,t}) = Mal_{e,u,t} \times \sum_{p_n} (Y_{e,p_n} \times P_{p_n,t})$$ *Market allocation equations for a unit (n,u,t)*

$$\sum_{p_u} (Y_{e,p_u,t} \times P_{p_u,t}) \geq A\mathrm{min}_{e,n,t} \times \sum_{p_n} (Y_{e,p_n} \times P_{p_n,t})$$

$$\sum_{p_u} (Y_{e,p_u} \times P_{p_u,t}) \leq \mathrm{Amax}_{\mathrm{e,n,t}} \times \sum_{p_n} (Y_{e,p_n} \times P_{p_n,t})$$

- ***Abatement Equations***

The degree to which an abatement technology is used for a particular process, is indicated by the abatement level. Environmental legal regulations oblige certain energy processes to be equipped with abatement technologies after a certain year, and emission equations limit the sum of all the emissions of a particular pollutant caused by the energy system. Also these regulations make necessary that certain energy processes are equipped with abatement technologies after a specified year. These regulations can be modeled with the following equations:

$$P_{p,t} \geq Abat_{a,p,t}$$ *Abatement technology equation*

$$\mathrm{Envreg}_{\mathrm{a,p,t}} \times P_{p,t} = Abat_{a,p,t}$$ *Environmental legislation equation*

$$\sum_{e} \sum_{n} \sum_{i} (Flowemiss_{c,e,i,n,t} \times R_{e,i,n,t}) + \sum_{e} \sum_{n'} \sum_{n} (Flowemiss_{c,e,n',n,t)} \times I_{e,n',n,t}) +$$

$$\sum_{e} \sum_{n} \sum_{d} (Flowemiss_{c,e,n,d,t} \times D_{e,n,d,t)+} \sum_{p} (P_{p,t} \times \mathrm{Procemiss}_{p,c} \,/\, \mathrm{Proceff}_{p}) +$$

$$\sum_{a} \sum_{p} (Abat_{a,p,t} \times Abatemiss_{a,p,c} \,/\, \mathrm{Proceff}_{p}) \leq \mathrm{Emissmax}_{c,t}$$ *Emission equation*

The parameters involved in the objective functions and the equations are defined as follows:

Cost-var	The variable costs are all costs proportional to flow, process level or abatement level. The costs include the variable operating and maintenance costs.
Cost-fix	The fixed costs represent all the operating costs proportional to the installed capacity.
Cost-inv	The investment costs represent the sum of all charges incurred to build one unit of capacity.
Pur-pric	The purchase price is only considered for the import of energy carriers. It represents the costs per unit of import flow.
Sel-pric	The selling price is only considered for the export of energy carriers. It represents the profits obtained per unit of export flow.
Life-tec	The technical life time of the equipment, expressed in years. The annuities are calculated for a refund period equal to the technical life time.
Irate	Interest rate.
Discrate	Discount rate.
$R_{e,i,n,t}$	Import/resource category i of energy carrier e to producer n at period t in [PJ/year]
$I_{e,n',n,t}$	Intermediate delivery of energy carrier e from producer n' to n at period t in [PJ/year]
$P_{p_n,t}$	Process level of Process p_n in period t in [PJ/year]
Y_{e,p_n}	Yield of energy carrier e in process p_n at period t Y_{e,p_n} = -1/efficiency p (if e is only input of p) Y_{e,p_n} = 1 (if e is only output of p)
$D_{e,n,d,t}$	Final delivery of energy carrier e from producer n for demand d in period t in [PJ/Y]
$Seas$	$= Pgs, Pgw, Bgs, Bgw$ = Index of peak, base load in Summer and Winter
n_e	Index of producer of electricity, heat or steam
e	Index of energy carrier of electricity, heat or steam
peak	Pgs, Pgw
base	Bgs, Bgw
$n_{e_{st}}$	Index of storage process, electricity, heat or steam

$Rl_{u,b,t}$	The number of years during which $CAPAC_u$, built in period b, still remains in period t
$year_t$	Number of years of period t
$BUI_{u,b}$	The capacity of unit u which is built in period b
$RESC_{u,t}$	The residual capacity of unit u is the capacity, which would be available in period t, if no new capacity was invested since the beginning of the planning period.
$Avaifac_u$	Availability factor of process p
$Convfac_u$	1 when CAPAC is expressed in PJ/Y, 0.0315 [(PJ/Y)/MW] when CAPAC is expressed in MW
$Outelec_{p_u}$	Electricity part of the output of process p, if there is electricity output, or else $Outelec_p = 1$
$Abat_{a,p,t}$	The abatement level of abatement technology a which reduces the emissions of process p during period t.
c	SO_2, NO_x, CO_2 = Index of emission
$Envreg_{a,p,t}$	The part of energy process p, which has to be equipped with abatement technology.
$Flowemiss_{c,e,i,n,t}$	Emission c belonging to the resource flow from i for n during period t
$Flowemiss_{c,e,n`,n,t}$	Emission c belonging to the intermediate flow of energy carrier e form n' to n in period t [ton/PJ]
$Flowemiss_{c,e,n,d,t}$	Emission c belonging to demand flow from n to d during period t [ton/PJ]
$Procemiss_{p,c}$	Emission c per Process input level p [ton/PJ]
$Proceff_p$	Efficiency process p
$Abatemiss_{a,c}$	Reduction of emission c per process output level [ton/PJ]
$Emissmax_{c,t}$	Upper bound of emission c during period [t]
$Mal_{e,p,t}$	The ratio between the process p output of energy carrier e and its unit output of the same energy carrier in period t.
$Amin_{e,p,t}$	Lower bound on the ratio between the process p output of energy carrier e and its unit output of the same energy carrier in period t.
$Amax_{e,p,t}$	Upper bound on the ratio between the process p output of energy carrier e and its unit output of the same energy carrier in period t.
$Mal_{e,u,t}$	The ratio between the unit u output of energy carrier e and its producer output of the same energy carrier in period t.

$A\min_{e,n,t}$	Lower bound on the unit u output of energy carrier e and its producer output of the same energy carrier in period t.
$\mathrm{Amax}_{e,n,t}$	Upper bound on the unit u output of energy carrier e and its producer output of the same energy carrier in period t.

2.3 Development of a Energy Planning Model for Iran

The EFOM-ENV model is applied in several countries with the purpose of development strategies for the energy systems in an efficient manner, whereby environmental problems play an important role. A key issue in this modeling procedure is the determination of appropriate technical, economical, and environmental parameters. This requires a comprehensive analysis of a country's economical structure such as available fuels, demand, geographical and climatic conditions etc.

The development of an adequate model to represent the situation in Iran requires the modification and adaptation of the existing model versions described in section 2.2. After analysis of the existing structure of the energy supply system in Iran and the techno-economic assessment, it is necessary to change the network structure of the model, i.e. changes in the aggregation level and exclusion or inclusion of technologies, which are applicable under Iranian conditions.

Then a detailed analysis of the energy conversion and emission control technologies has to be carried out, i.e. changes in technological and economic data of technologies or processes under Iranian conditions and the estimation of investment and operating costs. It is noted that a data base covering the whole Iranian energy system and also including future technological options for energy supply and emission reduction has not been available in the Iranian institutions responsible for energy planning. Therefore some energy related data and emission data has been extracted from the different official resources and the rest has been estimated from other institutions.

The changes in the objective function of the model should be carried out regarding the externalities of emissions and modifications in the emission equation in order to reduce the air pollution in Tehran. Also the specific problems like the limited availability of foreign currency and capital investment as additional restrictions have been introduced.

2.3.1 The EFOM-ENV Model Version for Iran

Most energy environmental tools are developed for industrialized countries. The lack of reliable and consistent data in most developing countries limits the usefulness of some of the more comprehensive and detailed models. An adequate energy environmental planning tool should reflect the developing country specific problems in the energy fields such as: rural/urban dichotomy, representation of non-commercial fuels, consideration of regional imbalances, interaction between energy and economy, management of non-renewable resources, and foreign currency requirements.

Between the above mentioned problems, consideration of regional imbalances, foreign exchange requirements and management of exhaustible resources are important for choosing an adequate energy environmental planning tool for Iran.

Iran is characterized by underdeveloped industrial infrastructures. Expansion of a large-scale system like the energy sector requires the importation of technology from industrialized countries. Development of the energy sector requires the construction of large extraction and conversion technologies, which are usually not within the technological capabilities of the country. Therefore, a large sum of foreign currency has to be allocated for the importation of the necessary extraction, conversion and transmission facilities.

The availability of foreign exchange is a major problem and may limit the development of the energy sector. A flexible tool for planning the energy and environmental system must be able to analyze the effect of foreign currency shortages on the structure of the energy system. The objective function of EFOM-ENV is the minimization of the total costs. These total costs must be defined as the sum of domestic costs and the foreign currency expenditure for operating and developing the energy sector. For the analysis of the foreign currency requirement, it is necessary to specify the domestic and foreign components of the total costs in the objective function explicitly.

In Iran, the economic and social infrastructure is unevenly distributed. While some regions like the capital city are heavily industrialized, others have a weak economy. Differences in the economic development of various parts of the country often result in different regional levels of energy demand. As a result, energy is also distributed unevenly in the regions. Many of the energy supply models represent only the technical dimension of the energy system. Homogeneity throughout the country or region is assumed implicitly. The application of such models for a developing country often requires modifications in order to add the regional dimension. The EFOM-ENV model is capable of considering regional imbalances of a country.

An adequate energy environmental planning tool should reflect the country's specific problems in the energy fields, such as foreign exchange rate, the consideration of regional imbalances and the externality effects on the development of emission.

The model must be able to analyze the effects of foreign exchange rates on the structure of the energy system. Therefore, the total cost is defined as the sum of domestic costs and the foreign components in the objective function of the EFOM-ENV model separately.

Cost-var = Dcost-var + Fcostvar,

Cost-fix = Dcost-fix + Fcostfix

Cost-fix = Dcost-inv + Fcostinv

Dcost-…	The total domestic variable, fixed and investment costs
Fcost-…	The total foreign variable, fixed and investment costs

The uneven distribution of the economic and social infrastructure in Iran results in different regional levels of energy consumption and demand. Consequently, the air pollution is concentrated in the large cities with a high energy consumption. The structure of the EFOM-ENV model is modified to consider the regional imbalances of the country. As the population and emissions are concentrated in Tehran, the model considers emission control strategies only for this city.

$P_{p,t} \geq Abat_{a,p,t,T}$ *Abatement technology equation for Tehran*

$Abat_{a,p,t,T}$	The abatement level of abatement technology a which reduces the emissions of process p during period t.

Air quality is an important factor influencing the health of Tehran's population. Therefore, the question arises, as to how far the total emissions must be reduced through the proper strategies in an efficient way. The question that must be answered are:

- Which energy conversion and emission reduction technologies should be applied to reach minimum costs in Tehran considering the externalities?
- Which effects of applying the externalities on the development of NO_x, SO_2 and CO_2 emissions and associated costs in Tehran can be expected?

An acceptable approach for Iran is to reduce the emissions in those cities where air pollution exceeds the WHO guidelines, like Tehran and to limit emissions to these standards. To answer the question of, how much are the emission reduction measures worth, the conflict between the energy supply costs in Tehran and these measures must be considered enforcing the externality effects in the model. The analysis of the impact of the externalities arising from the air pollution on the emission reduction strategies for Tehran needs some changes in the objective function of the model as follows:

$$totcost = \sum_t discfac_t \times (\text{Resource}Costs_t + DistributionCosts_t + DemandCosts_t + \text{Process}Costs_t$$
$$+ FixedCosts_t + InvestmentCosts_t + AbatementCosts_t + SocietalCosts_t)$$

$$\sum_e \sum_n \sum_i (Flowemiss_{c,e,i,n,t} \times R_{e,i,n,t}) + \sum_e \sum_{n'} \sum_n (Flowemiss_{c,e,n',n,t)} \times I_{e,n',n,t}) +$$

$$\sum_e \sum_n \sum_d (Flowemiss_{c,e,n,d,t} \times D_{e,n,d,t)+} \sum_p (P_{p,t} \times \text{Procemiss}_{p,c} / \text{Proceff}_p) +$$

$$\sum_a \sum_p (Abat_{a,p,t} \times Abatemiss_{a,p,c} / \text{Proceff}_p) \times costext_c \qquad \textit{Societal Costs}$$

which:

$Costext_c$ is the externalities of SO_2, NO_X and CO_2.

2.3.2 The Oil Sector

Considering the great importance of oil products for the energy system, the Iranian petroleum industry is developed largely and vastly. As Table 2-1 shows, Iran had eight refineries and one refinery complex with a total capacity of 1.45 million bbl/d[50] in 1999. Most of them were constructed more than 25 years ago and consequently have old technologies with designs from the past three decades, so that the loss of product are three times more than the current standards [122]. The Abadan refinery is the first of them which was installed about 90 years ago. The new refinery in Arak is the most modern facility of this kind in Iran which was constructed to produce lead free gasoline. The refineries in Tehran and Isfahan are presently at a higher level of production. Iran had plans to boost its refining capacity to about 2 million bbl/d by constructing two refineries including a 225,000 bbl/d plant at Shah Bahar and a 120,000 bbl/d unit on Qeshm Island. The US$3 billion Shah Bahar refinery project was approved by the government in late 1994 and the US$1.8 billion Qeshm Island refinery

[50] compared with developed countries like Germany whose total capacity is 1.85 million bbl/d.

project is to be built by Swiss company, Super Petroleum. Another 100,000 bbl/d plant is planned to refine crude oil from Kazakhstan and Turkmenistan by Belgian-based Unit International and its refined products will be purchased by the Iranian government.

The principal oil export terminal is located at Kharg Island. The crude oil produced in the south of the country is transported by pipeline to Kharg where it is stored in tanks with capacities of 250,000 barrels to one million barrels. The storage capacity of the island is about 20 million barrels and the loading capacity is 6 million bbl/d. The exports of crude oil produced from the oil fields in the offshore zone including Kharg, Lavan, Sirri and Bahregansar are handled by the special jetties with a capacity of 220,000 t.

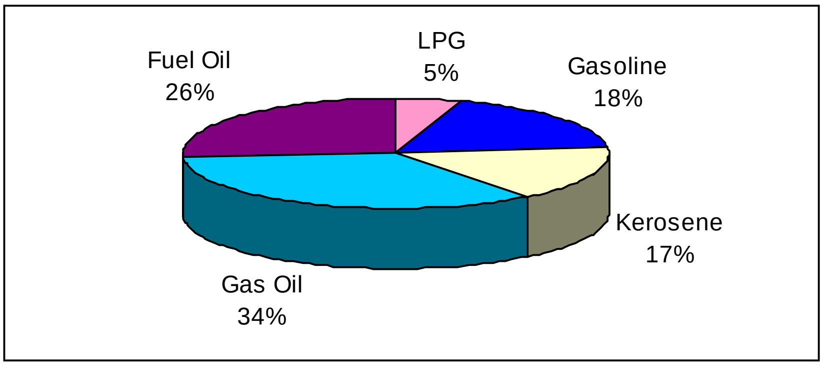
Pipelines from the oilfields in the southern parts of Iran to the local refineries transport crude oil and the refined oil products from the refineries are transported by pipelines, trucks, railway, tankers and tanker vessels to the storage depots. The length of the oil products pipeline network is over 10,000 km and it can transport over 245 million liters of oil products by the using 123 pumping stations.

Table 2-1: Nominal Capacity of the Refineries in Iran (1999)

Name	Type of Crude	Year of construction	Capacity (bbl/d)
Abadan	Heavy & Light	1912	370,500
Isfahan	Light	1970	335,000
Tehren	Light	1968	225,000
Shazand Arak	Light	1983	165,000
Tabriz	Light	1977	106,400
Shiraz	Heavy	1973	38,000
Lavan	Light	1975	20,000
Kermanshah	Light	1922	28,500
Bandar Abbas	Heavy	Planned	232,000
Total			1,450,000

The final products from oil refining have been aggregated into LPG, gasoline, gas-oil, kerosene and fuel oil. The expansion of the gas supply to the urban and the rural areas and the substitution of natural gas in many industries and power plants have changed the pattern of the consumption of oil products, and the middle distillates have considerably decreased compared to growth in the past decades. Figure 2-6 shows the consumption of the main oil products in 1996. Gas oil accounted for 34% of the total oil products consumed in 1996. The transport sector used 49% and the agriculture sector about 19% of gas oil in this year. Fuel oil was the second greatest oil product consumed with a share of 26%. Out of the total fuel oil consumption, 42% was used by the refineries and 30% by the industry.

Figure 2-6: The Consumption of Oil Products in 1996



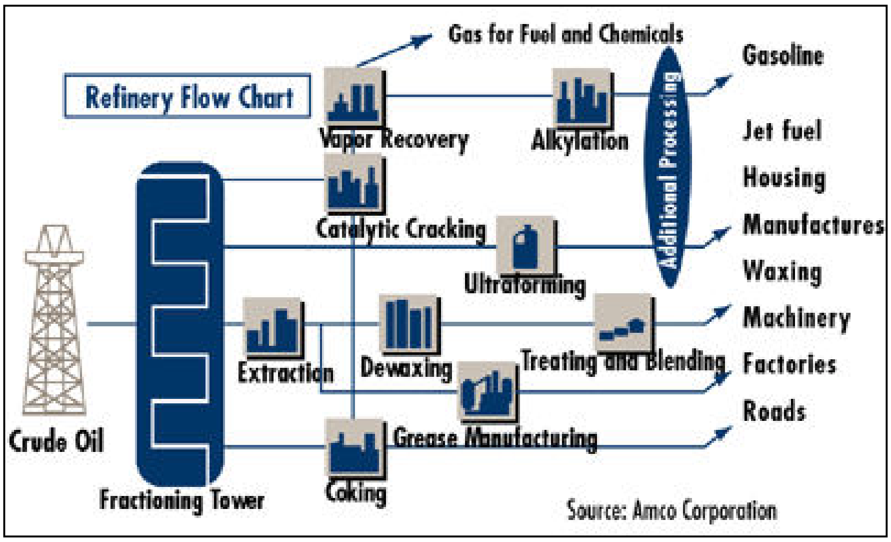
In order to meet the growing domestic demand for middle and light distillates, Iran has imported refined products since 1982. While these product imports reached more than 150,000 bbl/d in 1994, they have since subsided due to debottlenecking work at the Isfahan, Tabriz, Shiraz, and Lavan refineries during the past several years. In late 1996, Iran imported about 50,000 bbl/d light oil products and exported fuel oil and other heavy products.

Table 2-2: The Production Capacity of Oil Products in the Refineries (m^3/day) in 1998 [122]

Fuel	Abadan	Arak	Isfahan	Bandar.	Tehren	Tabriz	Shiraz	Lavan	Kermanshah
LPG	1720	807	2291	949	1245	601	241	111	98
Gasoline	5828	4080	6552	6423	5315	2011	1473	886	623
Kerosene	4329	3667	7981	3561	5190	2610	654	0	513
Gas Oil	14195	7608	14537	8598	10419	4580	2299	1863	633
Fuel Oil	27325	6026	11439	14952	9732	4328	1994	1748	1522

As Figure 2-8 shows, the petroleum sector is divided into three broad sub-systems: exploration and production of crude oil and natural gas; refining; and distribution. The aim of representing refinery process in the model is the control of the product composition obtained from the refining of crude oil. As mentioned before, in 1996 gas oil and fuel oil had the greatest share in oil production. Therefore the product composition can be changed either by the installation of cracking and other conversion plants to increase the share of lighter fractions.

Figure 2-7: Oil Refinery Process Diagram



All these activities in refineries (see Figure 2-7) have a variety of impacts on the environment. They include groundwater contamination from the connection between the production or waste injection zones and underground sources of drinking water, the release of hydrocarbons and hydrogen sulfide to the atmosphere, and decreased soil productivity from land spreading. Among these refineries, there is a complex plant of which the combination and sequence of its processes is usually very specific to the characteristics of the crude oil and the product. Catalytic cracking and reforming, thermal cracking, and other secondary processes are used to change the chemical composition of straight run fractions into usable products such as gasoline. Boilers, process heaters, and other process equipment produce emissions of particulates, carbon monoxide, NO_x, SO_2 and CO_2. Sulphur recovery units, combustion units and flares release SO_2, catalytic cracking regenerators release particulates, NO_x, and SO_2. Catalyst changeovers and cokers release particulates. VOCs are released from storage, product loading and handling facilities and oil /water separation systems.

According to the World bank calculations [230], the Isfahan refinery produces 44,000 t per year of SO_2 emissions and the Tehran refinery 100 t of SO_2 emissions per day releasing five times more than all of the vehicle traffic in this city.

Specific pollution prevention or source reduction measures can often only be determined by the technical staff. The different measures for the reduction of air pollution in the refineries can be considered as follows:

- Minimize losses from storage tanks and product transfer areas by method such as vapor recovery systems and double seals.
- Minimize SO_2 emissions by either desulphurization of fuels or directing the use of high sulphur fuels to units equipped with SO_2 emissions controls.
- Recovery of sulphur from tail gases in high efficiency sulphur recovery units.
- Recovery of nonsilica based (i.e. metallic) catalysts and reduce particulate emissions.
- Use of low NO_x burners to reduce the NO_x emissions.
- Avoidance and limitation of fugitive emissions by proper process design and maintenance.
- Maintaining fuel usage to minimum electricity and heat of a modern plant. Therefore, a more efficient cracking facility might be installed, if the higher investment can be financed.

2.3.3 The Gas Sector

Once natural gas is brought to the surface, it is refined to remove impurities, like water, gases and sand. Then it is transmitted through sizeable pipelines. The gas processing function begins at the well-head with the production of crude oil or raw natural gas. The casing-head gas and gas-well gas must be gathered, treated in the field, compressed and pipelined to a central facility for the final processing that will produce pipeline quality natural gas and marketable natural gas liquids.

As Table 2-3 shows, Iran has five gas treatment plants with a total process and treatment capacity of 207.9 million m^3 per day [122]. The processing capacity of the gas treatment plant has had an average growth rate of 5.5% annually during the past 20 years. Most gases entering the gas treatment plant carry some condensate, which is separated during the treatment process. The natural gas products from Khangiran gas fields have a high sulphur content, which is mainly in the form of hydrogen sulfide.

Figure 2-8: The Oil Subsystem

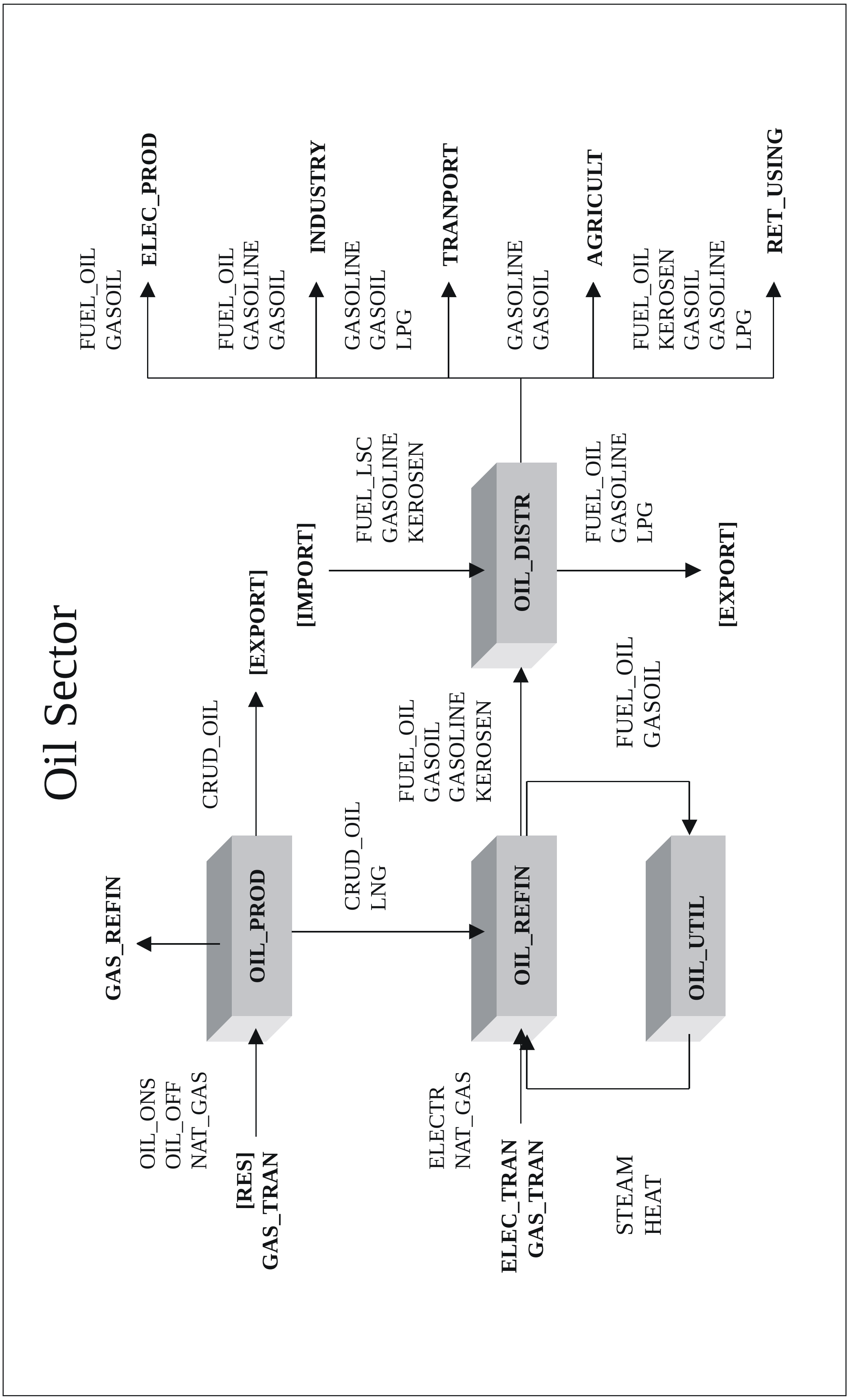


Table 2-3: The Gas Treatment Plant (1999) [122]

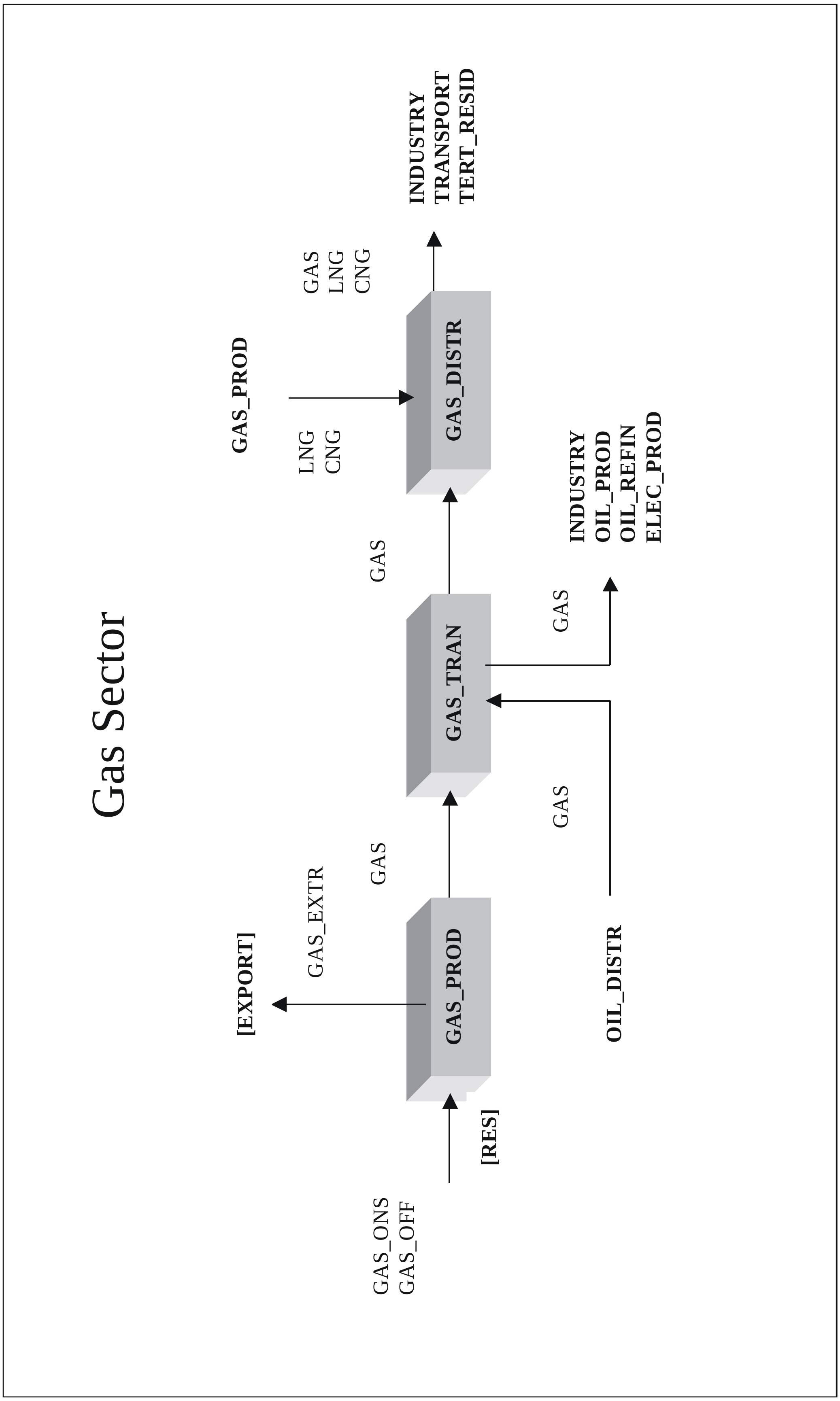
Gas treatment Plant	Year of construction	Capacity (Million m³/day)
Shahid Hashemi-nezhad	1983	31.30
Vali-e-asr	1989	89
Bid-Boland	1970	34
Sarkhoon	1989	14
Aghar & Dalan	1983	39.60
Total		**207.90**

A total 12,730 km of high-pressure pipeline of various diameters and 51,000 km of gas supply network had been constructed by the end of 1999. Gas is carried from the southern fields to the north via the 30- year-old first gas trunkline (IGAT-1) and from the Nar-Kangan area gas fields via the newer IGAT-2. The IGAT-1 pipeline was built for the dual purpose of exporting gas to the Soviet Union and supplying Tehran, Isfahan, Qazvin and other cities. Exports began late in 1970 under a barter deal whereby the Soviets provided Iran with a steel mill and other items in exchange for natural gas. After the revolution in Iran and following the world-wide rise in oil and gas prices, the Soviet Union did not make a new agreement. The specifications of the other pipelines are described in Table 2-4.

Table 2-4: The Gas Pipeline System [122]

Name	Origin (gas field)	Destination	Length of Pipeline
IGAT-1	Khuzestan	Centers in the north	42-inch 1106 km
IGAT-2	Kangan & Nar (Persian Gulf)	Bandar Taheri	56-inch 184 km
IGAT-3 (planned)	South Pars	Tehran	56-inch 510 km
Qeshm-Bandar Abbas	Qeshm Island	Bandar Abbas Power Station	12-inch 70 km
Sarakhs-Neka	Sarakhs	Neka power station in north-eastern regions	800 km
Sarkhun	Sarkhun	Copper Industry in Kerman Province	24-inch 400 km

Figure 2-9: The Gas Subsystem



The other system element in the gas sector is gas storage. The construction of underground gas storage is a necessary facility for ensuring a continued supply of gas to the demand sector in the various seasons. The seismographic studies for the determination of suitable and potential sites of underground natural gas storage facilities and the feasibility study began in 1996. Iran plans to construct oil and gas storage facilities with a total capacity of 50 kt in the north-eastern free economic zone of Sarakhs.

Figure 2-10: General Flow Diagram of Natural Gas Industry [47]

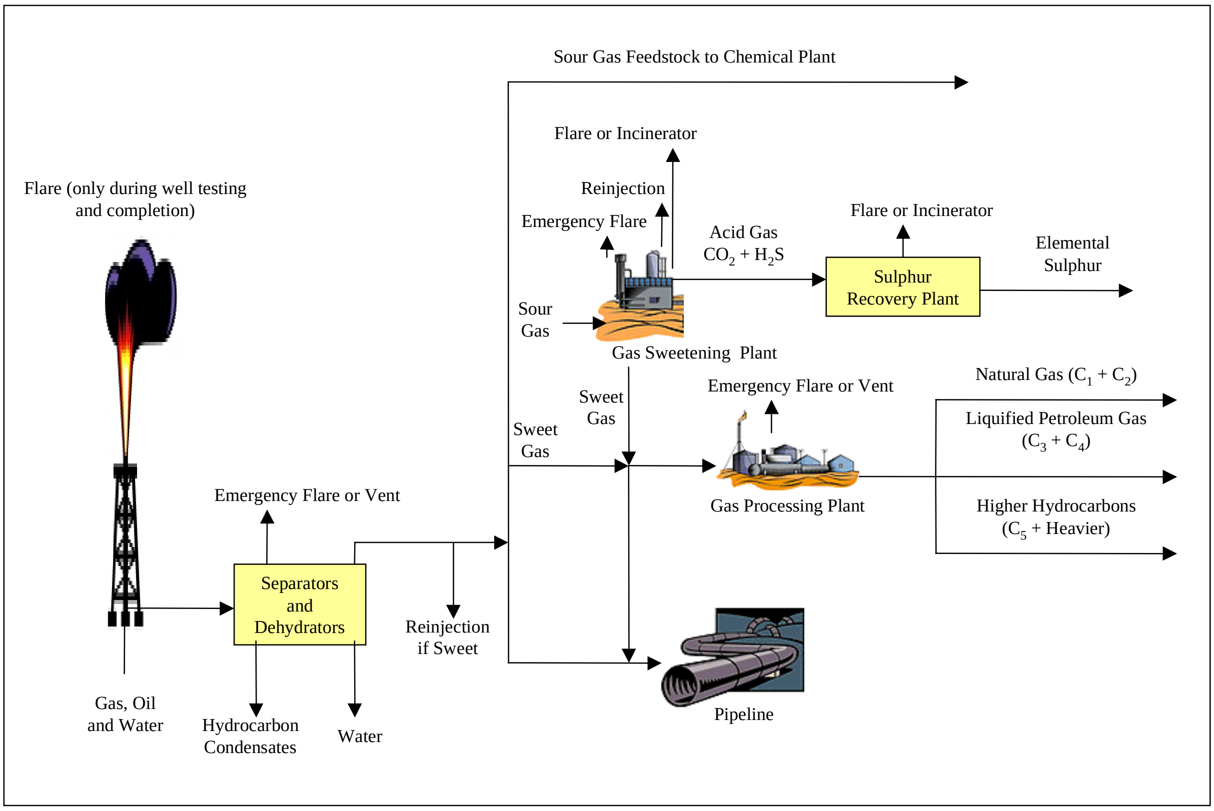


Figure 2-9 shows the gas sector in the EFOM-ENV model, which is divided into three sub-systems: production, transportation and distribution. The large industries and the electric power plants obtain gas directly from the pipelines but the residential and the small businesses and factories buy gas from the local distribution system. Final processing in the gas plant involves two basic operations (see Figure 2-10): extraction of the natural gas liquids from the gas stream and fractionation of the natural gas liquids into their separate components. Additional processing is usually required to treat and condition both the natural gas and the gas liquids. Natural gas processing may be as simple as drying the gas by passing it through a fixed bed of a desiccant material, or it may be as complex as complete liquefaction of the total gas stream by cooling to extremely low temperatures. Extraction of heavier gas liquids (pentane and heavier) can be achieved by simple compression and moderate cooling of the natural gas stream.

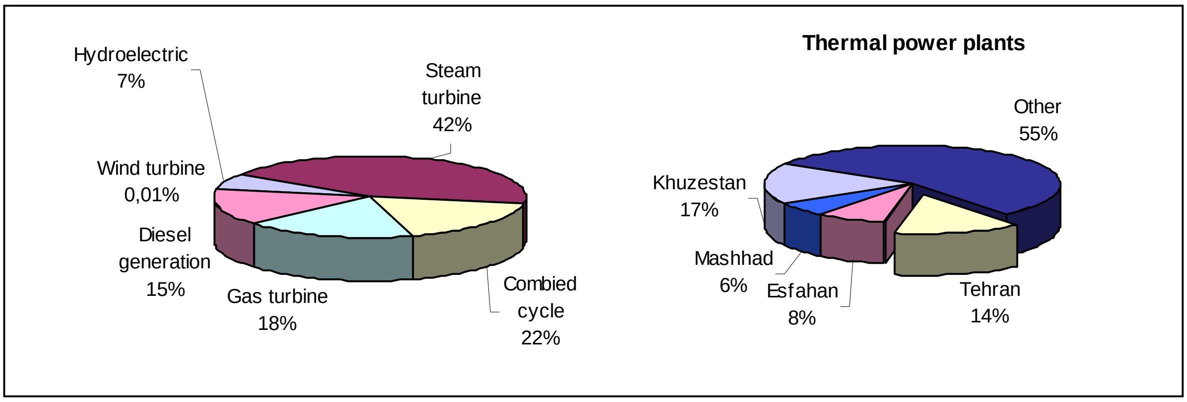
The major sources of air pollution consist of combustion equipment, vents, flares and fugitive emissions. These may contain VOC, SO_2, H_2S and NO_x. Emissions will result from the gas sweetening plant only if the acid waste gas from the amine process is flared or incinerated. Most often, the acid waste gas is used as a feedstock in nearby sulphur recovery or sulphuric acid plants. When flaring is practiced, the major pollutant of concern is SO_2. Gas flaring has been a major source of regional emissions, and for a few years during the early 1970s, before infrastructure was available for gas use and re-injection, flaring accounted for almost half of the total CO_2 emissions from fossil fuel. In 1951, there was very little prospect for an expanding gas industry in the world. The producers in the Middle East viewed the gas as an unwanted guest produced together with the crude oil to be disposed of by flaring it away and burning it up. After recognizing the importance of natural gas in the global energy requirements, the huge magnitude of the Iranian gas reserves became known and the necessary requirements of this new industry were developed in Iran. So that in the last few years, there has been strong growth in gas production and injection and a reduction in flaring.

2.3.4 The Energy Conversion Sector

The conversion sector uses the primary energy and provides electricity and heat for final consumption. The electric power industry in Iran is composed of state utilities including the central and de-central power sector and industrial producer. In the central power sector, electricity after production is fed directly into the public electricity grid. Some regions (Systan and Baluchestan) located far from the electricity network where connection to the grid is not economically feasible, use a local network for the distribution of electricity. This form of electricity production, which can satisfy a part of the electricity demand is described as a de-central power sector in the model. It characterizes the competition between centralized supply paths, making use of economies of scale at the expense of greater requirements for transportation, and decentralized systems, using small-scale power units on a local or regional level.

The total electric power capacity installed by the central and de-central power sectors in 1997 amounted to 29,897 MW [193]. The technologies used in Iran for electricity generation consist of gas/oil fired steam turbine power plants, gas turbine, diesel generators, gas-fired combined cycle power plants and hydro power plants. The traditional oil/gas fired boilers in the industrial plants are applied for the generation of heat and steam. As Figure 2-11 shows, the oil/gas fired steam turbine power plants account for 42% of the total installed capacity in the electric power generation, followed by a combined cycle with a share of about 22% and a gas turbine with 18%. Hydro power plants with 7% have the smallest share in electricity production. In 1998, the total decentralized power plants included 861 MW oil/gas fired steam power plant and 1887 MW gas turbine and combined cycle. Due to the concentration of industries and population in Tehran, about 14% of thermal power plants are situated in this region. As described in Table 2-5, the power utilities in Tehran are older than 25 years and consequently have old technologies and low efficiency [193].

Figure 2-11: The Share of the Different Power Plants in the Electricity Sector (1997) [192]



The policies behind the selection of technologies for the power utilities used to be completely different. In the 1980s, the government began to emphasize the development of steam power plants, as part of a plan to reduce hydroelectric power from 25% to 10% of the available energy by the end of the century [63]. Reversing this policy in the mid-1980s, the Ministry of Energy once again gave priority to hydroelectric power plants for reasons of environmental safety and higher productivity. So that, by the end of 1986, 17 dams were operating with a total energy generation capacity of 7,000 MW, i.e. 10% increase over 1985. In the period between 1993 to 1998, Iran changed its strategy again in the power sector and in order to meet the increasing electricity demand in the short-term, priority was given to the construction of gas turbines. While the current policy in the electricity sector is to increase of efficiency in the gas turbine power plants and change them to combined cycle power plants.

A large-scale solar-thermal power plant, a nuclear power plant, some wind converter parks, and a geothermal power plant are under construction and a coal-fired power plant is planned. As mentioned in chapter one, coal has less importance in the energy supply of Iran and up to now, has been used only in the steel industry. It is considered as a future option to electricity. Iran plans to build a coal power plant with a capacity of 1,500 MW in the north-west of the country in 2000. The required coal will be supplied from Tabas coal mine[51] in northwestern Iran. The aim of this project is to export the generated electricity to the neighboring countries.

Most technologies applied in the power utilities have been provided by foreign companies in Western Europe including Kraftwerk Union (a Siemens subsidiary), French-British GEC-Alsthom, Switzerland-based ABB Asea Brown Boveri, and Italy's Nuoca Cimimontubi and Belleli. Following the breaking up of the state power generation monopoly into private companies in 1998, Iran plans to use the participation of European and U.S. private investors in the planned privitization of the country's power generation industry.

Table 2-5: The Power Plants installed in Tehran [193]

Type of power plant	Name	year	Capacity (MW)	Efficiency	Total capacity (MW)
Steam turbine	Firuzi Montazer ghaem Besat	1960 1972 1975	50 625 288	23 32.14 30.53	963
Combined cycles & gas turbine	Firuzi Motazer ghaem Besat Rey	1965 1972 1977 1978	20 696 247.5 1243	23 29.11 22.39 22.59	2207
Diesel generation	-		7.6	29.46	7.6
Hydroelectric	Amir kabir Latian Besat	1961 1969 1983	74 44 70		188

51 Final Product: 750,000 t/yr Coal Concentrate in Phase I and 1,200,000 t/yr Coal Concentrate in Phase II [119]

Table 2-6: The Industrial Producers in 1997 [192]

Industry	Capacity of electricity production (MW)	Place
Isfahan Steel Mill (ISM)	165	Isfahan
Mobarakeh steel complex	210	Isfahan
Copper smelter	144	Sar Cheshme
Tractor manufacturing	20	Tabriz
Coal tretment	40	Kerman
Razi petrochemical	252	Imam port

The power sector has shown a general trend of declining technical efficiency over a 20 year period. The older power plants consume up to 44% more fuel per kWh of electricity produced than those in the OECD countries. Half of the power plants are more than ten years old and about 6,000 MW power plants are more than 20 years. The average efficiency of steam power plants is 33.5%, gas turbine 20.5% and combined cycle 31.7%. There is more than 20% of electricity production loss in the power utilities, transmission and distribution. The transmission and distribution system losses in the delivery of electricity are commonly greater than 15%. (In the United States only 8% of electricity is lost during transmission and in Japan about 7%.). These losses were equivalent to a capacity of about 5,000 MW or 20 billion kWh in 1998, which meant a loss of about two billion dollars a year through increased supply costs. According to the reports of the Ministry of Energy, reduce of losses in the transmission and distribution is not cost-effective considering the current fuel price in Iran.

Future development in the central electric power generation has been taken into account as follows: In addition to the current technology applied in the central power sector, pressurized fluidized bed combustion (PFBC) systems have been considered for the large-scale applications. For the de-central power sector, especially in rural areas with a low population, wind converters, diesel generators, photovoltaic, solar-thermal plants for power and heat generation have been planned into the model. Figure 2-12 shows the electricity subsystem which has defined in the EFOM-ENV model.

The industrial producers generate industrial process steam and electricity which is supplied directly to the industry or fed into the electricity network. In 1998, the large industrial producers had a capacity of total 831 MW including 375 MW steam power plants and 456 MW gas turbine power plants. Table 2-6 indicates the large industrial producers and their capacities in 1997. The other industries have a capacity of 6190 MW and use diesel generators which are not connected to the electricity network. Most of these industries including the refineries, chemical, petrochemical, iron and steel, sugar and wood industrie require high power capacity to meet their needs for process steam. There is no official detailed information about their type and exact capacities. Considering the development of the central power section, future development of the industrial producer has not been taken into account in the model.

Conventional heat and power generation is inefficient, only converting on average about a third of the potential energy of the fuel into usable energy. The dominant configuration of systems in the Iranian industries is boilers for steam generation. Considering the high growth rate in the electricity demand (about 7%), to increase efficiency in this sector, industrial heat and power cogeneration has been added as a future option into the model. This technology supplies district heat to the industrial sector through a distribution network and electricity into the public grid. The oil/gas fired combined heat and power (CHP) plants and geothermal heating plants have been considered for cogeneration and heat production. By the introduction of this subsystem for the supply heat, economic and environmental advantages, which result from highly energy conversion efficiency (with an overall efficiency of typically 80%) can be achieved.

For the development of cost-efficient energy supply strategies, the option ‘district heat from cogeneration’ must be put into competition with the energy chain ‘electricity from the centralized power generation plus heat from the industrial heating systems’. Due to the huge energy resources and low prices, comprehensive estimations in this field are lacking up to now. The information used in the model is extracted from the IIP resources.

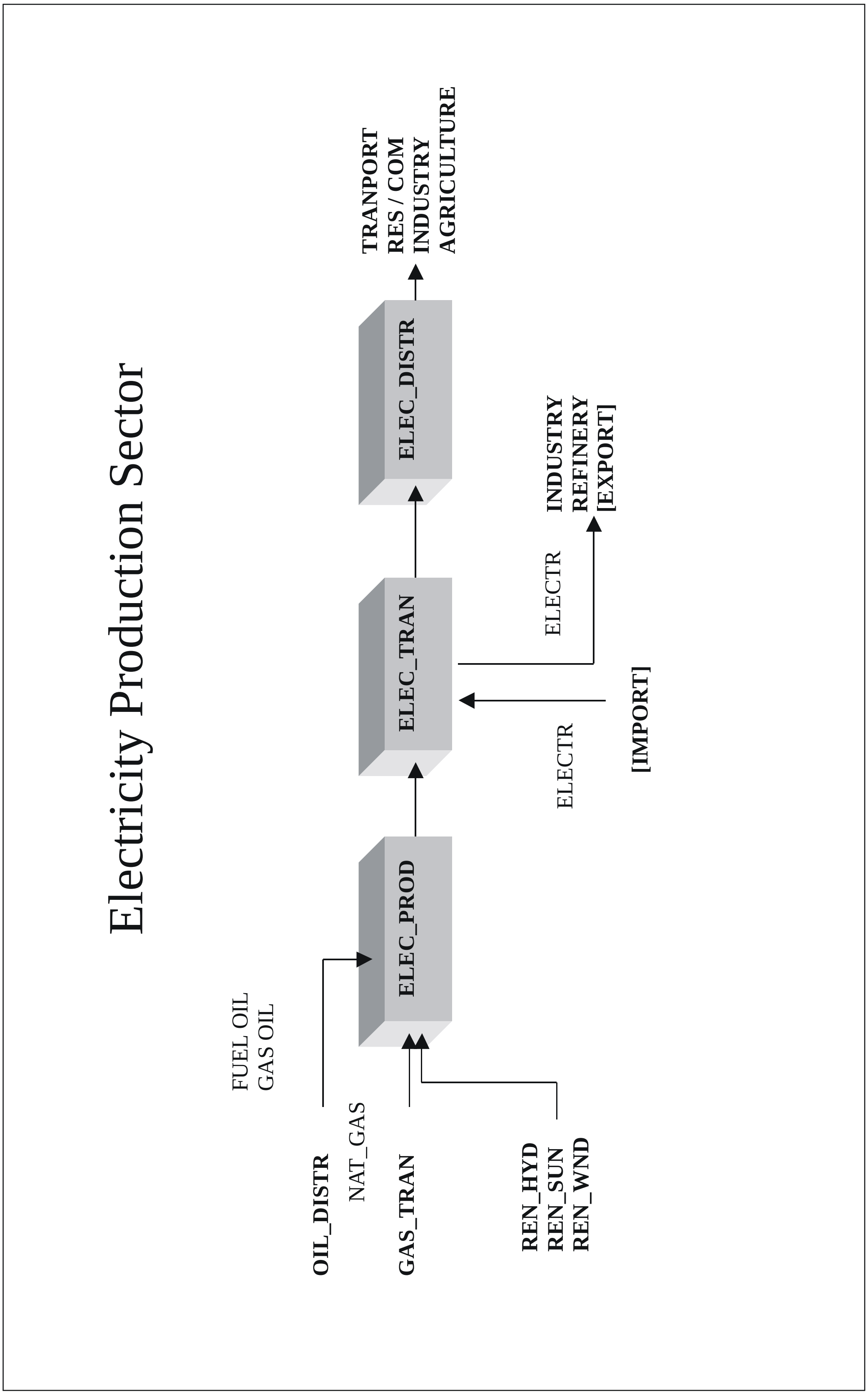
The electric power industry is one of the most polluting industries. The fossil fuel-combustion power plants, built in the 1960s, produce the vast majority of power plant air pollution in Iran.

2.4 Emission Reduction Components

2.4.1 Emission Factors

Emission factors and emission inventories have long been fundamental tools for air quality management. The estimation of pollutant emissions is important for developing emission control strategies, determining the applicability of control programs, ascertaining the effects of sources and appropriate mitigation strategies. In the model, emission factors are used to calculate emissions of the energy sector [144]. These factors are a representative or average value of data obtained from the facilities or processes in the same source category.

Figure 2-12: The Electricity Subsystem



The general equation for estimating emissions is as follows:

$$Emission = (ActivityRate)(EmissionFactor)(1 - \frac{EmissionReduction\%}{100\%})$$

Activity Rate	Magnitude of the activity per unit of time (1,000 kg coal burned/hour)
Emission Factor	Emissions per unit of activity (300g CO/ton coal burned)
Emission Reduction	Degree of destruction or capture efficiency of control equipment

The appropriateness of using emission factors varies from situation to situation. There are two possibilities as to how to introduce emission factors into the model:

- By using a fuel specific emission factor. The multiplication of the fuel flux with the emission factor results the emission. This approach, which is frequently used in inventorying, is not common in energy-environment models.

- By using technology specific emission factors. Each conversion technology obtains an emission factor depending on the fuel used and on the gross efficiency of the technology.

SO_2 and CO_2, which are mostly released from combustion processes, mainly depend on fuel properties. Nevertheless, with technology specific SO_2 and CO_2 emission factors, the share of the different sectors and conversion techniques of the overall emissions can be evaluated. On the contrary, NO_x emissions from combustion sources are strongly influenced by technology. Therefore emission factors for NO_x emissions should only be calculated for individual technologies and fuels.

- The SO_2 emission factors

The SO_2 emission factor is determined by sulphur content in the fuel. However, the content of sulphur in combustion residues is important. The SO_2 emission factors shown in Table 2-7 are obtained using the following equation and by using the analyses of the fuels in Iran:

$$ef_{SO_2} = \frac{C_1 S}{LHV}$$

ef_{SO_2}	Emission factor for SO_2 [t/PJ]
C_1	Conversion factor (=2) [1/wt.-%] (wt.% = weight percent total)
S	Sulphur content in fuel [wt.-%]

LHV Lower Heating Value of fuel [MJ/kg]

- The CO_2 emission factors

The CO_2 emission factor depends on the carbon content in the fuel. According to the type of fuel and technology, different amounts of carbon remain after the combustion process. The emission factor for CO_2 emissions shown Table 2-7 are obtained using the following equation:

$$ef_{CO_2} = \frac{C_1(1-u)}{LHV} C$$

ef_{CO_2}	Emission factor for CO_2 [t/PJ]
C_1	Conversion factor ($^{44}/_{12}$)
u	Different shares of the carbon contained in the fuels remain non-oxidized[52] due to the type of the fuel and conversion technique
C	Carbon content in fuel [wt.-%]
LHV	Lower Heating Value of fuel [MJ/kg]

- The NO_x emission factors

The NO_x emission factors calculated as NO_2 are influenced by parameters such as: the oxygen/nitrogen ratio in the fuel, size, and geometry of the furnace, combustion-air preheating, peak flame temperature. The emission factor for NO_x emissions is calculated by using the following equation:

$$ef_{NO_x} = \frac{C_1 C_2 (3.6 \, {}^{P}\!/_{P_0})^{0.18}}{\eta}$$

ef_{NO_x}	Emission factor for NO_x [t/GWh]
P/P_0	Normalized thermal power input
C_1	Unit conversion factor (=04104 t/GWh)

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52 The share of CO_2 in the residues is negligible in most cases. Investigations on the carbon, which remains uncombusted in the ash of coal fired power plants, have shown, that around one percent of the carbon of the fuel remain in the combustion residues. Compared to the uncertainty associated with LHV and carbon content of the fuel, it seems to be reasonable to disregarded the non-oxidised share of carbon [209].
u is carbon, which remains uncombusted, e.g. in the ash of coal fired power plant. Depending on the boiler used, *u* is between 1% and 2%. In most cases, it is assumed thet all the carbon is fully oxidized and converted itto CO_2 (i.e. u $\simeq$ 0).

C_2	Constant factor depending on the type of fuel and technology
η	Gross efficiency of the energy conversion technology [%]

Table 2-7: SO_2 and CO_2 Emission Factors used in the Model

	Lower Heating Value (MJ/kg)	Aver. Sulphur content (wt.-%*)	SO_2 Emission Factor (t/PJ)	Aver. Carbon content (wt.-%)	CO_2 Emission Factor (t/TJ)
Fuel Oil	41.03	1.5	731	85	76.0
Gas Oil	42.70	0.45	384	85.7	73.6
Kerosene	43.29	0.1	46.2	86.0	72.8
Gasoline	43.54	0.08	36.7	86.5	72.8
Gas	55.33	0.0022	0.8	84.5	56.0
LPG	46.0	0.002	0.88	82.0	65.4
Coal	31.08	1.0	643.5	83	97.9

* weight percent total (sulfur or carbon) in fuel

Table 2-8: NO_x Emission Factors for the energy sector in Iran

Sector	Type of fuel	NO_x Emission Factor (t/PJ), (t/GWh)[53]
Electricity	Gas oil	2.36
	Fuel oil	2.9
	Gas	0.54
	Coal	0.35
Industry	Diesel	60
	Fuel oil	170
	Gas	64-250
Residential/Commercial	Gas oil	60
	Fuel oil	120
	Kerosene	33
	Gas	45
	LPG	40
Agriculture	Gas oil	60
	Fuel oil	120
Transport	Gasoline	980
	Gas oil	1360

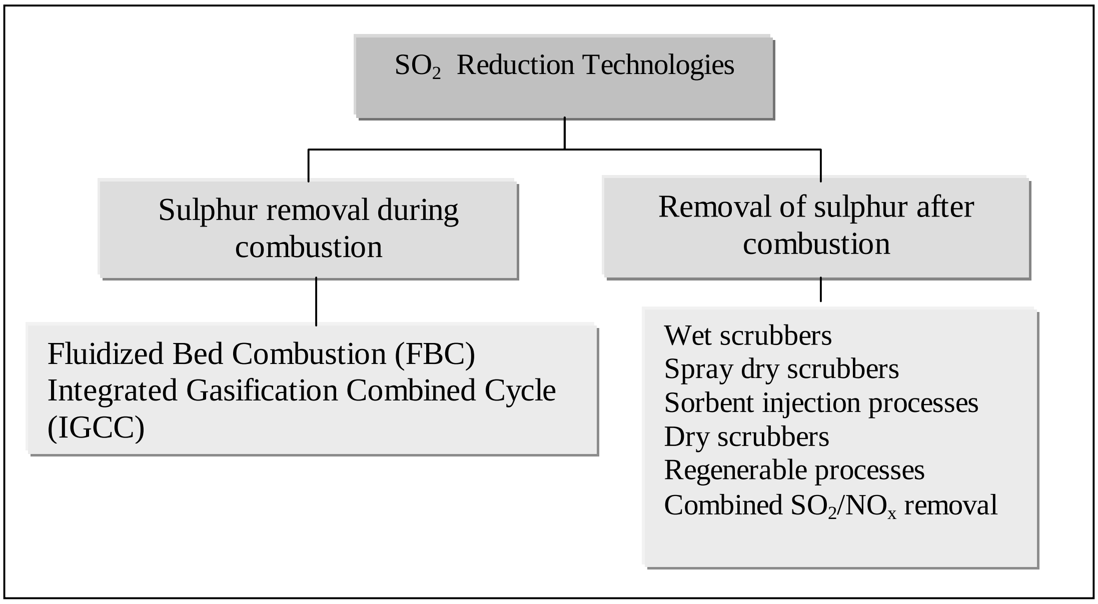
[53] (t/GWh) are applied only for power plants.

Table 2-8 shows the NO_x emission factors for the energy sector in Iran. As there is no official information on the combustion technology and operating condition in Iran, the NO_x emission factors have been extracted from the World Bank report [230] and the IPCC[54] guidelines [49].

2.4.2 SO_2 Emission Reduction Technologies

The use of emission control technologies depends on country specific conditions, such as the energy supply structure, economic and environmental situation. In addition, market aspects have a significant effect on the implementation process. SO_2 emissions arise from the oxidation during combustion of the sulphur contained within the fossil fuels. The reduction of SO_2 in the atmosphere is directly related to the control of the SO_2 emissions for the industry and technology. Actually, the major contributor of SO_2 are coal-fired power plants, accounting for almost 70% of the total emissions in the world in 1996. A reduction in atmospheric emissions of SO_2 produced by fossil fuel combustion processes can be achieved at one of three stages: before combustion, during and after combustion ([15][36][145] [154]).

Figure 2-13: SO_2 Control Technologies



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- ***Reducing the Sulphur Content of Fuel before Combustion***

One of the simplest ways to reduce the amount of SO_2 emissions can be achieved by switching to a fuel which has a lower sulphur content, i.e. combustion low sulphur oil or gas instead of high sulphur oil. Considering the huge reserves of natural gas in Iran, the cost of this method is relatively low. The reduction of the amount of sulphur normally found in fuel, particularly in crude oil and in heavy fuels is complicated and expensive, especially fo Iran. According to the report of the Ministry of Energy [193], the cost of desulphurization amount to US$ 1.8 per barrel for kerosene, gas oil and gasoline and US$ 7 for fuel oil.

- ***Preventing the Production and Release of Sulphur during Combustion***

Figure 2-13 shows the most developed technologies for SO_2 removal during combustion that are commercially applied, the Fluidized Bed Combustion (FBC) process and the Integrated Gasification Combined Cycle (IGCC) system. Both methods are applied for the desulphurization of coal-fired power plant flue gas. They are considered for the future coal power plant in the EFOM_ENV model for Iran.

Fluidized Bed Combustion is a technology for combustion coal, lignite and also low-grade fuel like wood, peat and waste. In this method, a dry additive is fed directly into the boiler in a pulverized form, where it reacts with gaseous pollutants to form salts.

IGCC technology is based on the gasification of coal with steam to produce a fuel gas which after the removal of sulphur, nitrogen and particulates, is fed to a gas turbine. The turbine exhaust is passed through a heat recovery system to generate high-pressure superheated steam. The overall efficiency (up to a possible 52%) and superior gas clean-up (more than 99% of sulphur and ash and 90% of nitrogen pollutants) lead to lower greenhouse gas and pollutant emissions in comparison with conventional boilers.

- ***Removal of Sulphur after Combustion***

By treating the flue gases from the boiler, SO_2 emissions can be reduced before they reach the stack and are emitted into the atmosphere. This process, termed Flue Gas Desulphurization (FGD), can be classified as regenerable or non- regenerable based on the way the sorbent is treated after it has absorbed SO_2. Within the non- regenerable system the reagent used to remove the SO_2 is not recirculated, while in the regenerable system the sorbent is recirculated and reused to absorb further SO_2. The regenerable processes can achieve high SO_2 removal efficiencies (up to 98%) but they generally involve high capital costs and power consumption. Most FGD systems (more than 85%) are non-regenerative and utilize lime or limestone.

- Wet Scrubbing for SO_2 Control

The wet scrubber technology is the most proven and commercially established SO_2 removal process in most of the developed countries (Europe, Japan, and the United States) and can achieve removal efficiencies as high as 50-99%. Wet scrubbing uses calcium-, sodium-, and ammonium-based sorbents and mostly produces marketable gypsum as by-product. At the end of 1993, there were more than 132 GW installed capacity operating worldwide. This technology has been considered for the oil and gas power plants and the future coal power plants in the EFOM-ENV model for Iran.

- Dry Scrubbing for SO_2 Control

Spray dry scrubbing are the second most widely used FGD technology. This technology has been used commercially with low sulphur coals in Europe and Japan and approximately 6% of the FGD systems in the United States (3600 MW). Spray dry scrubbing in commercial use have achieved a removal efficiency in excess of 90% with some suppliers giving more than 95% SO_2 removal efficiency as achievable. An efficiency of 70 to 95% removal of SO_2 has been achieved with low sulphur coals. Their application is limited to the flue gas volume from about 200 MW plants on average. The capital cost requirements for this method are less than those for wet scrubbers and simpler and easier to operate and maintain. The by-product of this process is a mixture of calcium-sulphate/sulphite and fly ash.

- Wellman Lord (Sodium Sulphite)

The Wellman Lord process has been applied successfully in power stations and chemical plants in Germany, Japan, Austria and the United States, whereby different fuels (oil, hard and brown coal, petrol coke) with a sulphur content of up to 3.5% have been burnt. The technology needs a high capital investment compared with wet scrubbers and can achieve high SO_2 removal efficiencies to 98%.

The process removes SO_2 from flue gas with a sodium sulphite scrubbing solution. Dry, concentrated SO_2 from the regeneration can be converted into a useful byproduct in the form of liquid SO_2, sulphuric acid, or elemental sulphur. The process also has the advantages that it does not require the consumption of large quantities of sorbent because of regeneration.

2.4.3 Available NO_x Reduction Strategies and Technologies

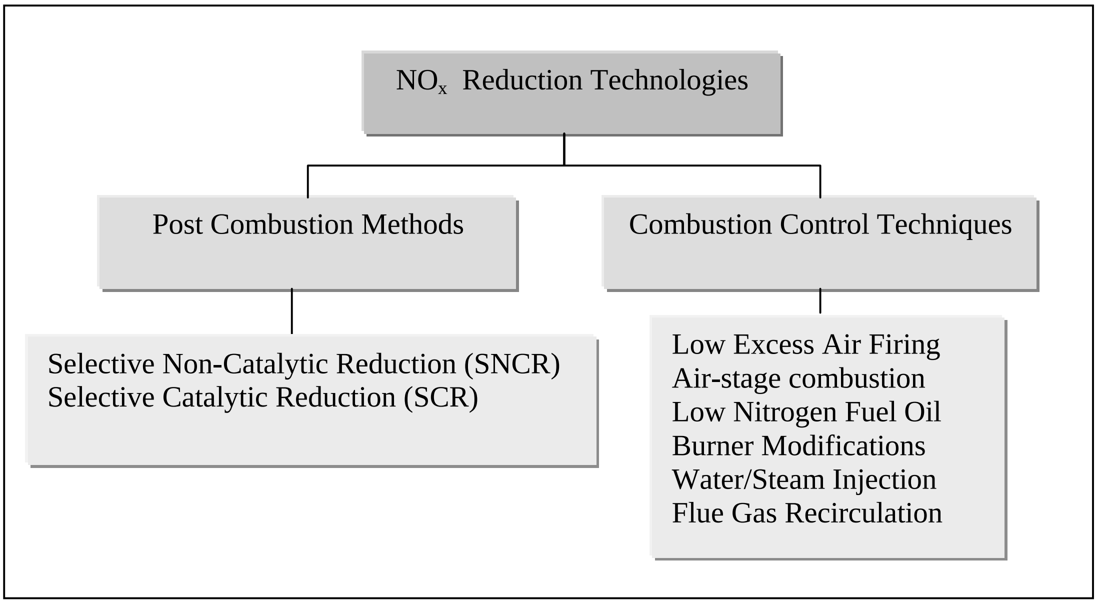
As Figure 2-14 shows, NO_x controls can be classified into two types: post combustion methods and combustion control techniques. Post combustion methods address NO_x emissions after formation, while combustion control techniques prevent the formation of NO_x during the combustion process. Post combustion methods tend to be more expensive than combustion control techniques and generally are not used on boilers with inputs of less than 105 GJ/hr.

Fuel switching is not very effective way for reduction of NO_x emissions because of the N_2 contained in air. However low nitrogen oil can contain up to 15-20 times less fuel-bound nitrogen than standard oil.

- ***Combustion Control Techniques***

Combustion control techniques reduce the amount of NO_x emissions by limiting the amount of NO_x formation during the combustion process. Combustion control techniques usually are more economical than post combustion methods. These include namely burner modification, Low Excess Air (LEA) firing, Air-staged combustion, Flue Gas Recirculation (FGR), gas reburning, Low NO_x Burners (LNB) and water or steam injection.

Figure 2-14: NO_x Control Technologies



- ***Post Combustion Methods***

One of the important methods for removing NOx emissions derived from the combustion of fossil fuels embodies their conversion to inert nitrogen gas and water vapor by reduction with reductant compounds in processes such as Selective Catalytic Reduction (SCR) or Selective Non-Catalytic Reduction (SNCR).

In the SCR, the reduction of NO_x by the injected reagents such as ammonia or urea is enhanced by the presence of catalysts. The SCR achieves 80 - 90% reduction of NO_x emissions. The SBCR involves injecting reagents as ammonia or urea in the furnace. The reduction efficiency of both SNCR and less advanced combustion controls is lower (40 - 50%). Advanced combustion control achieves 60 - 70% reduction of NO_x emissions. The SCR system requires more cost for each ton of NO_x reduction than SNCR. The most cost-effective, and the most affordable technologies are the less advanced combustion controls that do not reduce the total amount of NO_x emissions.

In terms of by-products or other pollutants, both SNCR and SCR can lead to ammonia (or urea) emissions. An SCR system usually emits less ammonia (about 10 ppm) than an SNCR system. In addition, an SCR system consumes more energy since it is an add-on system thus increasing CO_2 emissions. Finally, the catalysts from SCR systems may have to be disposed of as special waste or recycled.

2.4.4 CO_2 Control Measures

CO_2 emissions can be reduced through a variety of measures, such as the utilization of various less carbon-intensive or carbon-free energy resources, the promotion of renewable energy sources, improvements in the efficiency, energy saving and the disposal and recycling of CO_2 in the energy systems. The EFOM-ENV model for Iran takes into account the following categories of measures excluding the removal and storage of CO_2 ([55][159]):

- Energy Efficiency Improvement

Energy efficiency improvement is generally viewed as the most important short-term CO_2 mitigation option. It is considered as a reduction of the specific energy consumption which is defined as the amount of energy needed to perform one unit of a specific operation (e.g. to heat one m^3 of space, to produce a ton of steel or to transport a ton over a distance of 1 km). The technically feasible potential for energy efficiency improvement in the Iranian energy sector is described in chapter one.

- Fuel Switching

The change from oil products to natural gas can contribute significantly to CO_2 reduction. Considering the huge reserves of natural gas in Iran, switching to this fuel has also economical and environmental advantages. Naturally, the rapid expansion of gas pipelines requires corresponding investment.

- Nuclear Energy

A significant contribution to the reduction of CO_2 emissions is possible by the use of nuclear energy. However several aspects connected to the use of nuclear energy have to be considered such as the safety of the reactors and a solution for handling the radioactive waste and the proliferation risks. The official plans for expansion of nuclear power plants are considered in the model.

- Renewable Energy

The contribution of renewable energies could be considered for various CO_2 emission reduction targets. Iran has a high potential for renewable energy development but this energy is only partially developed to a commercial status. A review of the technical potential of the renewable energy in Iran, described in chapter one, shows that solar energy provides the greatest potential. Although the costs of electricity produced by solar photovoltaic systems are somewhat higher than electricity from the grid, it is expected that solar energy could become competitive with electricity from the grid within several decades, especially in regions with a high irradiation.

- Clean and Efficient Conversion of Fuels

The clean and efficient conversion of fossil fuels can reduce CO_2 pollution. Capable technologies for the improvement of the conversion efficiency in electricity production consist of gas turbines, fuel cells, integrated cycles with gas turbines, fuel cells and steam cycles and the gasification of coal, waste, biomass or even oil. Electricity conversion efficiencies up to 60-70% are achievable. However, the worldwide electricity conversion efficiency is about 33% and in Iran about 30%.

Technologies for the improvement of the conversion efficiencies for the production of steam and heat are combined heat and power production (cogeneration) and heat pumps. Heat pumps can upgrade low temperature heat and can be applied in buildings (for heating, hot water and cooling) and in industry. They strongly increase the efficiencies compared to normal boilers. Cogeneration can be applied as district heating and in industry. Through the combined generation of heat and power, energy is saved. The efficiencies in cogeneration can be improved, mostly as a result of improving the electric efficiency but also by improving efficiencies of heat exchangers. This option is considered for the future energy supply in the EFOM-ENV model for Iran.

- CO_2 Removal and Storage

The measure not considered in the model is carbon dioxide removal. It is the recovery of CO_2 from energy conversion processes and the storage or disposal outside the atmosphere, e.g. in depleted oil or gas fields, aquifers or the deep ocean. It would be interesting for the oil exporting countries in future, especially for Iran with its vast gas fields. Most attention has been given to the recovery from the electricity production, but in industrial processes CO_2 recovery is possible too.

2.5 Environmental Externalities

The exploitation of any energy source generates externalities, defined as societal costs that are not reflected in market transaction [99]. The impact of air pollution can generally be classified into four major categories: health impact, work productivity effects, ecosystem impacts, and aesthetic effects. All of these are commonly encountered examples of economic externalities.

An externality has no direct monetary effect on the producer of goods, but influences the standard of living of society as a whole. It can bring positive or negative consequences. A positive externality is something beneficial for society, but in such a way that the producer cannot fully profit from the gains made. A negative externality is something that costs the producer nothing, but is costly to society in general. Pollution represents a negative externality because the damage associated with it is born by society as a whole and is not reflected in market transitions. The issue of negative externalities is most prominent in the public utility business. For example, when the cost of electricity is calculated, factors such as the price of the fuel operating expenses of the power plant, are taken into account. All of the costs of the potential problems associated with climate change, weather changes causing floods or drought etc. are not costs that are or will be borne by the energy producers.

Air pollution has become a significant and increasing problem in many large cities of the developing countries. Pollution levels in these metropolises are already worse than those of some industrial countries. The inhabitants of such cities are also more likely to suffer from the detrimental health effects that can result from breathing polluted air. The developing countries generally have been much slower than the industrial countries in recognizing the risks and in taking technical steps to reduce air pollution from automobile and industrial facilities.

As the government in Iran is the major owner of large industries, it is required to internalize externality costs. This means that if a industry's pollution creates economic costs (for example, the medical bill of a patient who gets sick from pollution), then the government has to pay that cost. In this way, the government can more accurately compare revenues and expenses and decide how far emission reduction technologies are required. Although, there is the question of placing a monetary value on such things as death, extinction, the destruction of forests, and many other social costs.

2.5.1 Health Effects of Air Pollution

Major costs of air pollution arise from its effects on human health. According to the WHO [237], air pollutants associated with the combustion of fossil fuels: particulates, CO, NO_x, and SO_2 are linked e.g. to impaired pulmonary function, respiratory illness, and premature mortality. In people exposed to the pollutant for long periods, nitrogen dioxide also has effects on breathing and respiratory system, damage to lung tissue, premature death. Small particles penetrate deeply into sensitive parts of the lungs and can cause or worsen respiratory disease, such as emphysema and bronchitis, and intensify existing heart disease. SO_2 affects people quickly, usually within the first few minutes of exposure. Studies indicate that SO_2 exposure can lead acute health effects. Exposure is linked to an increase in hospitalizations and deaths from respiratory and cardiovascular causes, especially among asthmatics and those with pre-existing respiratory diseases. Also, both gases may be altered in the atmosphere to become fine particulates in the form of sulphates and nitrates, or acid rain when combined with water. Acidic contaminants can affect human health directly when inhaled, and indirectly when they fall on surface water, land and plants. Increasing levels of CO_2 could adversely affect the earth's weather, a gradual warming trend around the globe.

On a global basis, estimates of mortality due to outdoor air pollution run from around 200,000 to 570,000, representing about 0.4% to 1.1% of the total annual deaths [230]. High concentrations of air pollutants in many developing countries lead to increased illness, particularly among individuals suffering from respiratory problems, and cause premature death. Air pollution in the developing world cities is responsible for some 50 million cases per year of chronic coughing in children younger than 14 years of age.

Air pollution in the Iranian capital city is often so bad that the Department of Environment has to issue a public warning. The government warning pertains not only to children and the elderly, but also to people with heart conditions and asthma sufferers. In general, air pollution in metropolitan areas annually averages 5 to 8 cases of severe respiratory infection threatening children under five. But, this rate is 10 in Tehran (one child per month) due to the high rate of air pollution. The volume of Tehran's air pollutions is two to ten times more than the World Health Organization's guidelines causing 4,000 deaths per year from pulmonary diseases in Tehran. This is in addition to 3,000 people who contract cancer each year in the capital city [230].

Also, a preliminary study by the World Bank in Iran [230] shows a high correlation between high ambient air concentration levels of TSP and SO_2 and headaches and bronchitis in school children in Tehran. In this study annual premature deaths and morbidity in Iran are estimated at 18,000 and 7,000 persons respectively by 2010.

2.5.2 Ambient Air Quality Standards

Air quality standards essentially identify levels, with an adequate margin of safety, beyond which a pollutant can cause harm. Ambient standards are concerned with the overall air quality of a community or industrial area and specify allowable pollutant concentrations in such areas. Ambient air quality standards are often subdivided into primary and secondary standards. The primary standards are intended to protect human health and have a margin of safety, whereby economic and technical feasibility are disregarded. Secondary standards refer to environmental effects and are intended to protect overall or long-term human welfare. They pertain to visibility, soil, water, vegetation, domestic animals, wildlife, materials, property, transportation, and economic issues. Secondary standards can be attained at a more leisurely pace ([230][232]).

Many countries have set air quality "limit values". These may be presented as national standards or recommended air quality guidelines. Iran has begun to deal with air quality control only recently and does not have national air quality standards. The most comprehensive air quality guideline has been provided by the WHO Regional Office for Europe. It provides guideline reference material for 23 air pollution compounds, concentrating on the health effects of those pollutants. For certain pollutants for which there is no threshold below which there are no observable effects, the WHO provides exposure effect information, illustrating the major health impact of different levels of the pollutant. In the developing countries with heavily polluted areas, these guidelines may serve as long-term objectives, however, short-term actions should be guided by a careful analysis of the expected benefits and costs of pollution abatement measures. In practical terms, this leads to temporary, achievable ambient quality objectives.

Table 2-9: WHO Air Quality Guidelines [237]

Compound	Annual ambient air concentration [µg/m³]	Observed effect level [µg/m³]	Uncertainty factor[55]	Guidline value [µg/m³]	Averaging Time
NO_x	10-150	365-565	0.5	200	1 hour
				40	1 year
SO_2	5-400	1000	2	500	10 minutes
		250	2	125	24 hours
		100	2	50	1 year

The other valid ambient air quality standard is set by the U.S. Environmental Protection Agency (EPA). Some of these standards could be adapted in the developing countries. EPA publicized national primary and secondary ambient air quality standards for six "criteria" pollutants: PM, NO_x , SO_2, Pb, O_3 and CO.

2.5.3 Economic Analysis of Environmental Externalities

Since air pollution imposes costs on society, the identification of these pollutants and the assessment of their impacts, both monetary and non-monetary, are important elements in the economic analysis of the benefits and the costs of various production alternatives. Information on the costs of pollution is also important in helping to decide what level of pollution control is economically justified. The externalities are identified as part of the environmental assessment, quantified where possible, and included in the economic analysis as project costs or benefit. After assigning a monetary value to the costs and benefits, they are entered into the cash flow just as any other costs and benefit ([75][76]).

Many analysts have attempted to quantify the societal costs of pollution and other externalities associated with fossil fuel combustion, and some have even attempted to crudely

[55] In development of these guidelines, the size of uncertainty factors applied to published data in deriving a guideline was considered to be a matter for expert judgement, rather than prescription (WHO 1987). Where the database was strong, smaller uncertainty factors were used than where the database was weak. Database strength depends upon the availability of published studies relevant to the circumstances of a country for which the guidelines are intended. In moving from guidelines to country-specific standards, the size of the uncertainty factors may require revision [237].

incorporate externality costs into investment decisions. Estimates of externality costs are often based on quite different assumptions, making comparison difficult [99]. There are huge uncertainties in assessing externality costs related to emissions, and the exact values of these costs can probably not be determined. The estimates vary as a function of population density, geographic and meteorological conditions, and other factors. Some of the most important effects might be impossible to quantify.

Various methods are available for valuing environmental externalities ([41][48]). The choice of valuation technique depends on the impact to be valued, data and time available for the analysis, financial resources and the social/cultural within which the valuation is carried out. Some valuation approaches are more robust, and more likely to be applied.

The public health costs of air pollution from energy consumption are also uncertain, but are likely to be very high. Considering the fact that these costs have not been integrated into either the market or the energy producer, it has been necessary to avoid a costly externality in their economic decisions. In many developing countries, the data-gathering system is poorly funded and the data tends to be weak. Epidemiological data is also not assembled in a scientific manner.

Table 2-10: The Externalities of Power Plants [171]

Type of power plant	Externalities (Rials/kWh)
Fuel oil steam	86.6
Gas steam	33
Coal steam	94.8
Combined Cycle	22.7
Fuel oil Gas Turbine	85.3
Gas Turbine with Gas fuel	35.1
Cogeneration (Electricity)	30.9
Cogeneration (Heat)	2.4

Several methods are used in practice to value health costs associated with environmental pollution. These methods can be divided into two broader categories [230]. The first one includes methods that measure only the loss of direct income. The second category includes an attempt to use the Willingness-To-Pay of individuals for avoiding or reducing the risk of death or illness. Although they seem to be uneconomical, a “human capital” approach is necessary that estimates the present value of the future earnings of an individual that would be lost due to premature mortality. The difficulty arises when one compares estimates between countries, especially countries with very different income levels. For example, if results of Europe are applied, it must be considered that Europe’s population density is different from the population density of Iran and the average income in Iran is about 10% of the income in west Europe.

Table 2-10 shows the externalities of air pollution in Iranian power plants [171]. The Ministry of Energy has obtained a preliminary estimation from the results of EPA’s research. These costs are adapted to conditions in Iran and calculated with US$1 = Rials 3000. The externalities for SO_2, NO_x, and CO_2 emissions are estimated as Rials/kg 2640, Rials/kg 19272, and Rials/kg 72.6 respectively [192].

3 Basic Assumptions and Definition of Scenarios

Scenario planning helps to raise awareness of several plausible future possiblities. The technique consists of making consistent assumptions about the future outcome of existing trends and patterns. The purpose of scenario planning is not to predict the future but rather to show how different forces can manipulate the future in different directions. It is important to realize this, for this procedure helps to identify these forces if and when they happen. The utility of scenario planning lies in its ability to anticipate the future. When this is accomplished, the ability to better respond to future events is increased ([30][224]).

In energy environmental studies, to cover the problem of uncertainty about future developments, various scenarios have to be defined. Scenarios are defined for different assumptions concerning the development of e.g. the final/useful energy demand, world market energy prices, discount and interest rates, technical developments of new technologies etc. In this way, different emission control policies or strategies are examined. The results obtained from the application of the energy model are valid only under the restriction that the set of assumptions on these parameters reflects the actual future development. It is a “what if” analysis. The sensitivity of the achieved results can then be investigated by analyzing similarities/differences of the solutions obtained. Of course, due to feedback in-between the scenario assumptions and between the assumptions and the model results, the consistency has to be checked carefully.

In this study, different scenarios are described concerning the development of major energy parameters, different emission control objectives related to the most polluted region and externality effects.

3.1 Basic Assumptions for Scenario Analysis

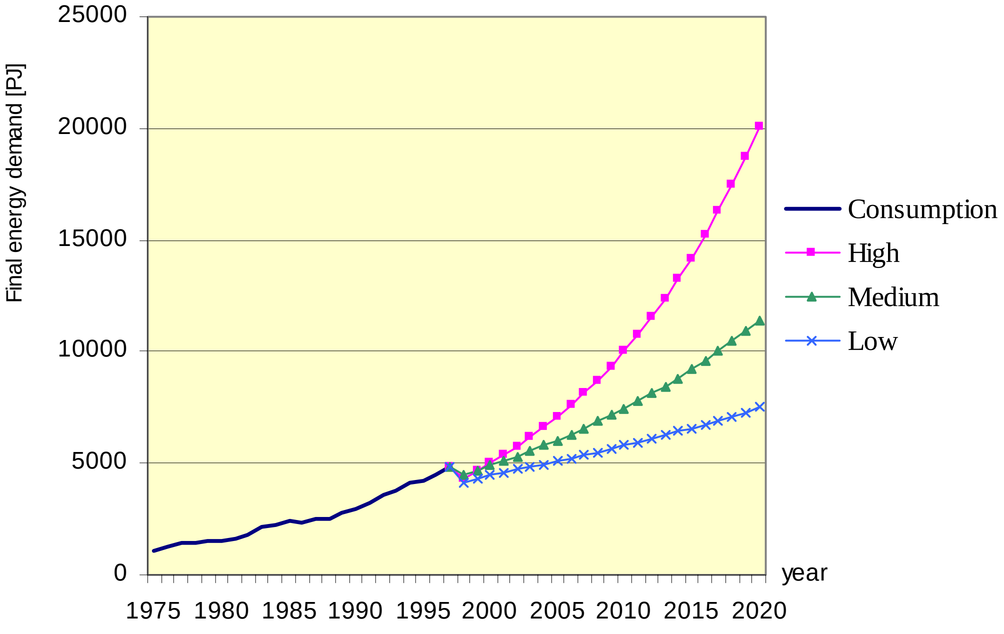
The amount of data available, the reliability of the data, and the timeliness of the data are positively related to the stage of economic development of the country. It is clear that the lack of reliable and consistent data in Iran like most developing countries limits the usefulness of some of the more comprehensive and detailed models. The data necessary for constructing the model are basically taken from the reports published by the Central Bank of Iran, the Ministry of Oil, the Ministry of Energy, the Plan and Budget Organization and the World Bank ([192][193][86][122][229]). However, there are common problems such as inconsistency of data and discrepancies in the ranges of data included in the statistical sources.

- ***Energy Demand***

The projection of the future energy demand plays an important role in the analysis of the energy-environmental models. The results influence the choice of emission reduction measures and subsequently their final costs.

The energy demand projection for this study has been taken from the official forecasts of the Iranian Ministry of Energy. As Figure 3-1 shows, three different scenarios have been defined, low, medium and high. The basic assumption has been described in section 1.3.2. It has been assumed that GDP grows 6% p.a., which is close to the medium scenario of the Plan and Budget Organization (PBO) projection. The Plan and Budget Organization has forecasted three possibilities for the growth of GDP in the Third Five Year Development Plan, 5%, 6.2% and 7.7%, although the average annual growth rate of GDP was 1.7% over the period 1975-97 ([87][88]).

Figure 3-1: The Final Energy Demand Forecast for Iran



The projection of the energy consumption in the high demand scenario shows a significant rise in energy demand with an average growth rate of 7.2% p.a. This rate is 4.3% and 2.6% for medium and low scenarios respectively. In view of the fact that the energy consumption has increased with an average annual rate of 6.4% over the last 20 years due to the urbanization, development and the high population growth, it seems to be an underestimated value in the projection of low demand scenario.

This forecast applies as a basic assumption, considering the fact that it reflects the official forecast. In the reference case of the model, it has been assumed that final energy demand will increase according to the medium scenario. In the high demand case, the high forecast has been considered as a basis and naturally the low forecast has been applied in the low demand case.

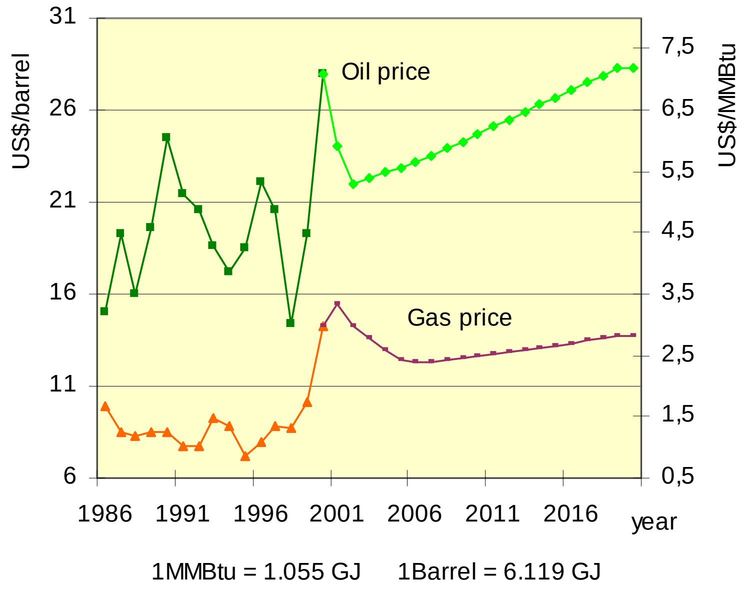
- ***Energy Price***

As stated in chapter one, the huge energy reserves (oil & gas) and the state ownership are the reasons for the fact that a change in the international crude oil price does not play a key role in meeting the energy requirements in Iran. The fluctuation of the oil price influences the amount of foreign currency and changes the government’s revenue. A strong dependency of the Iranian economy on the oil revenue and the decline of the oil price can lead to serious economic tension, particularly in the economic sections. The decrease of foreign currency revenue from the sale of oil can affect the economy in a number of ways, whereby the severe budget deficit and the shortage of foreign currency are the most obvious. For example, Iran spent an average of US$1.6 billion annually for the import of equipment, parts, materials and additives for the oil and gas industry during the First Five-Year Development Plan. The industry sector supplies 50% to 60% of the equipment required by the oil industry. In 1977, Iran met less than 5% of the oil and gas industry's requirements through domestic production, and imported the rest [192].

Figure 3-2 shows the development of oil and gas price in the international market during the period 2000-2020. The price of crude oil fluctuated strongly in past years due to situations, which could not be predicted [110]. In this study, it is assumed that the crude oil price will increase steadily to reach about US$28 per barrel[56] in 2020 and the gas price will reach US$2.81 per MMBtu[57], although it seems not possible to make a precise forecast regarding oil prices.

[56] US$4.58 per GJ
[57] US$2.66 per GJ

Figure 3-2: The Forecast of Oil and Gas Prices [110]



The average price of fuel in Iran is only $^1/_8$ of the world price, i.e. the price is lower than production costs. The price of fuel had increased by 20% every year by the end of the second Five Years Development Plan. The government implemented the policy of gradual price increase and the reduction of subsidies as they had the least social impact, but due to a general increase in prices compared to the cost of energy, the fuel price remained fixed. It is assumed that the energy price in the medium demand energy scenario will increase gradually reaching the real cost during the third Five Year Development Plan. The real cost used in the EFOM-ENV model for Iran is shown in Table 3-1.

Table 3-1: Energy Price in Iran (Rials)

Energy	Unit	Sale Price (1998)	Real Cost* (1998)
Fuel Oil	liter	40	270
Kerosene	liter	60	490
Gas Oil	liter	200	510
Gasoline	liter	60	490
Gas	m³	60	140
Electricity	kWh	32.36	130

* energy cost without subsidizing

- ***Planning Period***

As described in section 2.2, the time horizon usually covers the next 20-30 years. Taking into consideration rapid changes and uncertainties in the energy world, prices, demand etc., the time horizon in the study has been chosen as 20 years. This is also the time-period, for which the results of the final energy demand projection model are determined. The year 1998 has been chosen as the base year due to the availability of a detailed energy system analysis. The latest official statistics on the energy sector published by the Ministry of Energy are accessible for 1998. Therefore, the optimization period for the elaboration of cost-efficient emission reduction strategies is defined for the period between 1998 and 2020.

- ***Actual Foreign Exchange Rates***

Other important economic parameters, which influence the economic evaluation of different energy and emission control processes, are the actual foreign exchange rates and the discount rate. For the expansion of a large-scale system like the energy sector it will be necessary to import technology from the industrialized countries. Therefore, a large sum of foreign currency has to be allocated for the import of the required extraction, conversion, and transmission facilities. The availability of foreign currency and a multiple exchange rate[58] system is a major problem for the development of the energy sector. The evaluation of energy projects gives various results for the different exchange rates.

For the analysis of the foreign currency requirement, it will be necessary to specify the domestic and foreign components of cost in the objective function separately. Therefore the evaluation of energy projects will give different results for different exchange rates, resulting in different future supply structures. Considering the substantial fluctuation in the exchange rate during the post revolution period, the official exchange rate of 1998 for exports, which amounted to 3000 Rials per US$ was taken as a basis in the model and the results are compared with the exchange rate of the Tehran Stock Exchange which amounted to about 8000 Rials per US$.

- ***Discount Rate***

Different “official” interest rates are applied in the Iranian bank system. These rates vary from 6% to 24% for national money and is fixed at 3% for foreign currency. Due to the high inflation in Iran, the minimum interest rate of return in non-state sectors is 30%. The average

[58] see section 1.1.5 : The Exchange Rate System

rate of inflation is predicted to be about 15.9% during the third Five Year Development Plan, while the inflation rates were 36.5% and 23.2% in 1995 and 1996 respectively. The highest rate of inflation during the post- revolution years ensued in 1994 at 51%. It should be noted that inflation rate was 28.9% in 1988, a year before the First Five Year Development Plan started. The comparison of the expected inflation rate during the years of the Third Plan with that of the last five years, when it was at 26.5%, is an indication of the major direction to be taken in the Third Plan towards the objective of creating economic stability.

Therefore proper discount rates are difficult to forecast and there are no surveys concerning the choice of a proper discount rate. In the model, the basic value of the discount rate has been fixed at 16% for national money and 3% for foreign currency.

3.2 Definition of Scenarios

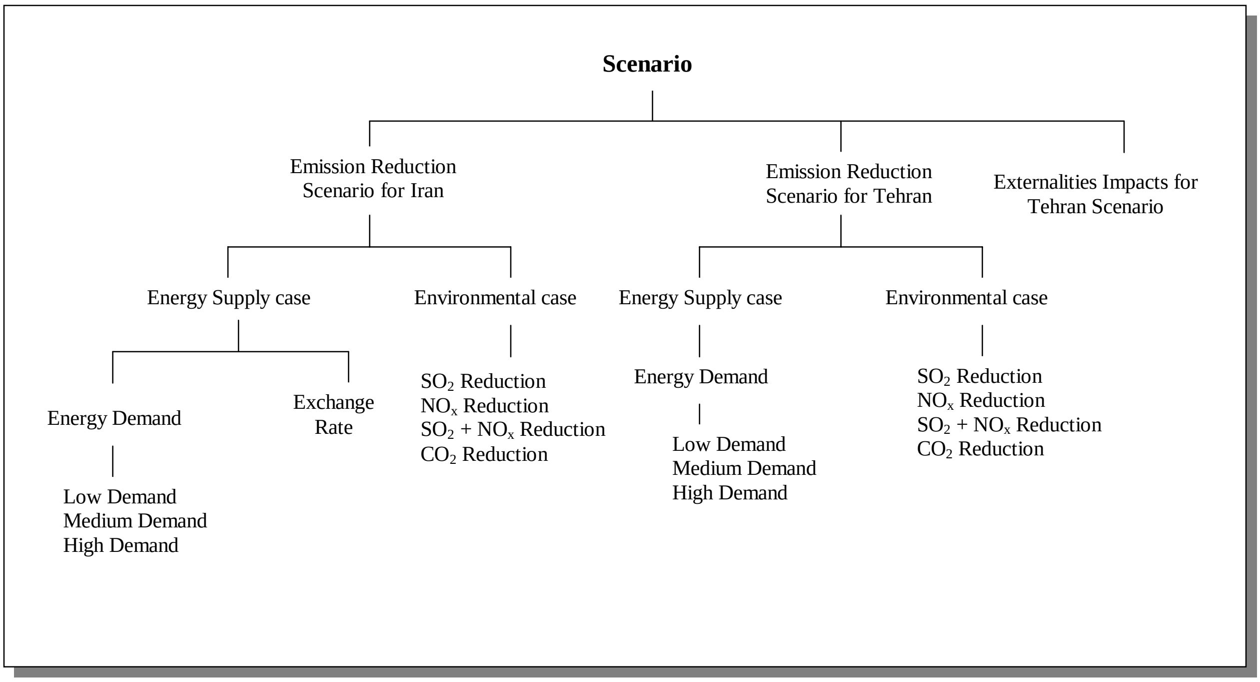
3.2.1 Emission Reduction Scenario for Iran (Reference Scenario)

In this study three scenarios have been defined as Figure 3-3. The first case is the reference case, which forms the basis for determining differences in the results of the two other scenarios. For each scenario, a cost-efficient energy supply and emission control strategy has been determined by applying the model. The study has compared different assumptions on important input parameters.

The reference scenario has been defined with and without emission control restriction. This reference scenario serves as a basis for the analysis of different energy supply and emission control strategies and the effect of variations in important input parameters. The results of the model for energy supply and emission control strategies have been used for analysis and evaluation of the results of the application of the modified model for Tehran. The impact of externalities arising from energy consumption in Tehran on emission control strategies has been analyzed.

All the basic assumptions introduced by reference case are applied in the two other scenarios, the emission reduction scenario for Tehran and the externalities impacts scenario for Tehran. The development of the energy supply structure and its effects on air pollution, which are reflected by the results of the reference case, help to define the emission control measures and reduce the costs of the different emission control strategies.

Figure 3-3: The Different Scenarios Defined in the Study



The main assumptions for the reference scenario are taken from the third development plan with parameters such as the final energy demand, the price of fuel, the actual exchange rate of US$ and the discount rate. In the energy supply case for the emission reduction scenario for Iran, no emission control measures are considered during the planning period. There are no limitations on the availability of foreign currency either. These variations in the above mentioned parameters are described as follows:

- In the emission reduction scenario for Iran it has been assumed the final energy demand will increase according to the medium scenario of the demand forecast. The energy consumption will rise from 4483 PJ in 1998 to 11362 PJ in 2020, i.e. a 60% increase in the consumption of energy compared to 1998.

- The crude oil production capacity will increase slightly and reach 4.4 million bbl/d by the year 2004 [46]. Iran needs over US$30 billion in investment only for its oil sector to maintain the current capacity (3.6 million bbl/d) and to explore new oil fields. Considering the financial limitation of the government, it is assumed that the production capacity will reach 6 million bbl/d by the year 2020.

- The price of crude oil and gas will increase in accordance with the price forecast in Figure 3-2 during the study period.

- The average annual foreign currency generated from the sale of crude oil will be calculated considering the amount of production and its price for the period of planning.

- Considering the importance of the actual exchange rate for interpreting the results of the energy planning model, a high dollar case has been defined, reflecting the exchange rate of the Tehran stock exchange in 1998, where the real exchange rate of the US$ was about three times the reference case i.e. the official export rate. Although the official export rate does not show the actual exchange rate of the US$, the government uses this rate to support strategic sections like the energy system.

- The discount rate changes from 16% in the reference case to 24% and 8% in the high and low case, respectively. The higher rate is the same as the rate of returns on investment of the state-controlled projects in the Tehran stock exchange. The lower rate is applied in national plans in order to develop the infrastructure of the country. Considering the high inflation rate in Iran, it seems that a high rate is closer to reality but a 16% discount rate can have positive external effects on the energy sector. Therefore it has been chosen as a reference case in the model.

3.2.2 Emission Reduction Scenario for Tehran

Formulating the emission control strategies generally has a lower priority than the economic development in Iran. Given the priorities and constraints, Iran cannot achieve the same clean air controls as the many industrialized countries in the short or medium term. But Iran must plan to achieve minimum levels of clean air. A balance must be struck between what is desirable and what is achievable.

Considering the geographical status of Iran and the growth of population and the increased concentration of industry in and around some large cities, as described in chapter one, this scenario focuses on emission reduction in Tehran. The emission control strategies involve the identification of cost efficient emission control measures and the related emission control costs in order to develop strategies to minimize the total energy costs in Iran and the environmental costs of energy production and consumption in Tehran.

As the minimization of the energy and environmental emission control costs in the basic model take the entire energy sector, some parameters in the objective and restriction functions must be changed in order to limit the emission reduction measures only for the region of Tehran. The emission equations control the sum of the emissions of pollutants caused by energy production and consumption in Iran and Tehran separately. The changes in the abatement technology equations have been carried out in the data entry structure.

This scenario will concentrate on SO_2, NO_x, and CO_2 emissions separately. The emission control measures and their costs resulting from the emission reduction scenario for Tehran will be compared with outcomes of the emission reduction scenario for Iran. The required emission reduction has been defined as the amount assumed in the integrated master plan for the air pollution control in July 1998 in Tehran. The master plan, which is enforced by the Air Quality Control Company (AQCC) affiliated to the Tehran Municipality will cover an area of 2500 square kilometers. In this plan, it has been estimated that Tehran's air pollution problem would worsen by 2015 if nothing was done to reduce emissions. The projections also showed that the introduction of less polluting vehicles and fuels would see pollution levels remaining at 1995 levels by 2015, while the introduction of improved public transport and less polluting vehicles and fuels would be the most effective solution. In this study no specified restriction of emission reduction level has been defined but by gradually increasing the required reduction of total emissions, it will reach a maximum feasible level. For each emission reduction level the related emission control costs will be identified, which has been determined for both separate and combined SO_2, NO_x, and CO_2 emission reduction in Tehran.

Although certain technologies have not been considered to reduce CO_2 emissions and the capacity of CO_2 emissions reduction is not calculated for Iran, energy efficiency and saving measures have been taken into account to reduce CO_2 emissions. The maximum level of CO_2 emissions reduction depends on the potential of energy saving in Iran and the measures, which will be applied for the reduction of SO_2, and NO_x emissions.

The same basic assumptions considered by the Emission Reduction scenario for Iran have used in the Emission Reduction scenario for Tehran. The medium energy demand scenario has been applied to define the emission reduction strategies for Tehran.

3.2.3 Externalities Impact Scenario for Tehran

The increased air pollution resulting from the expansion of industry and the growth of energy demand in the large cities is threatening human health and undermining the productivity of the urban population. The Mitigation of adverse environmental and health effects associated with economic development through timely and cost-effective programs should be a high priority for the countries like Iran, for both local and global reasons. The challenge for these countries is to benefit from the experience of the industrialized countries, avoid their mistakes, and establish the basis for sound economic development while preserving human health and the quality of the environment.

Air quality is an important factor influencing the health of Tehran's population and the sustainability of Iranian cities. Therefore the general aim of the externalities impact scenario is to create a basis on which to improve the urban air quality and reduce the health risks from the air pollution. Evaluations of the environmental impact of energy production plans should illustrate the effects on health and safety. Naturally, the need to mitigate the health impacts of air pollution is incontestable, but air quality management will have a lower priority than other programs.

The approach used to achieve this objective involves the assessment of environmental externalities, the assessment of control options, and the comparison of costs of damage and the costs of control options. From this, an action plan can be set up containing the selected abatement measures for implementation in the medium/long term. To achieve the above aim, the externalities are added to the objective function. By adding this parameter to the objective function, the emission equation in the restriction functions will be eliminated.

The same basic assumptions considered in the Emission Reduction scenario for Tehran have been used in the externalities impacts scenario for Tehran. The externalities of NO_x, SO_2, and CO_2 emissions are applied in the model as described in chapter 2.5.3.

3.3 Limitation of the Approach

The EFOM-ENV model has some weak points despite its flexibility and simplicity ([11][12][26][121]). Firstly, the linearity nature of the model permits for only close estimates of existing non-linearity in the energy system. However, non-linearity exists in the real energy system, for example, the relation between the electricity production and the power capacity in reservoir hydro power plants or the relation between the heat to electricity ratio and the capacity of cogeneration power plants.

The other limitation of the EFOM-ENV model concerns the integer variables, i.e. mainly the capacity variables. The model specifies only an optimal amount of the total capacity, not minimum or standard capacities of plant types. The existence of certain standard (and minimum) capacities for the industrial processes can be taken into account in the other version of the EFOM-ENV model. As described in chapter 2.2.1, a version of the EFOM-ENV model has been developed to solve this problem by setting the restrictions such as minimum values and defining the capacity variables as integer variables [107]. This model is designed for use in small countries and for analyses, which require the consideration of single conversion processes or single emission sources in the optimization process.

Secondly, the model ignores the economies of scale, which are non-linear for most aspects of energy production. It means that the method disregards the fact that process parameters that are not independent of size. Due to this weakness, the application of such models is critical for the analysis of the energy systems, where single processes have a significant influence on total costs or emissions of the analyzed system.

The model cannot consider uncertainties and unresolved sub-aspects of the problem, such as those related with the atmospheric transportation of air pollutants. However, almost all decision problems involve some level of uncertainty either regarding data measurements, the values to assign to the parameters describing future evolution or even regarding the environment in which one has to operate. Data uncertainty in the model may occur due to the high volume of data, and simple typing errors, although they can be avoided to a certain extent by data management software [77]. A moderate change in the input data may give rise to extreme changes in the optimal solution of the problem. The limited availability of data and the incomplete information, resulting in the need for estimations, make the results more or less accurate.

Data uncertainties appear due to the representation of technologies in the model. The parameters and data used to represent a fuel or technology in the model are average figures, unable to represent the conditions for a specific fuel or plant. This applies for example for the investment expenses of hydro power plants which vary depending on site-specific factors.

Another inadequacy is related to the problem of incomplete foresight of future developments. The model takes the demand as given and does not investigate the impacts of using prices and other instruments of energy demand management to bring demand and supply into balance. By analyzing the model results for a variety of scenarios, robust decisions can be identified, which are insensitive to changes in important parameters. But all prognoses or scenarios assume a more or less steady future, while in reality an unexpected variation of parameters occurs and this model is not so flexible to such sudden changes. Flexibility may be regarded even as an objective and can be achieved by the diversification of energy sources and technologies to achieve a distribution of risk.

Another problem is the contribution of export revenues from energy to the objective function particularly for the oil exporting countries. The optimal utilization of resources and development of an appropriate resource pricing policy will either contribute to the increase of foreign currency revenues (from the export of these resources) or to the decrease of energy imports, and consequently helps to reduce the foreign currency requirement. The Model cannot provide an optimal solution considering the needs of energy export. In the case of a large oil exporting country like Iran, this modeling feature would lead to false conclusions for the domestic market. It would, therefore, be necessary to analyze the utilization of exhaustible resources for the domestic and for the export market separately.

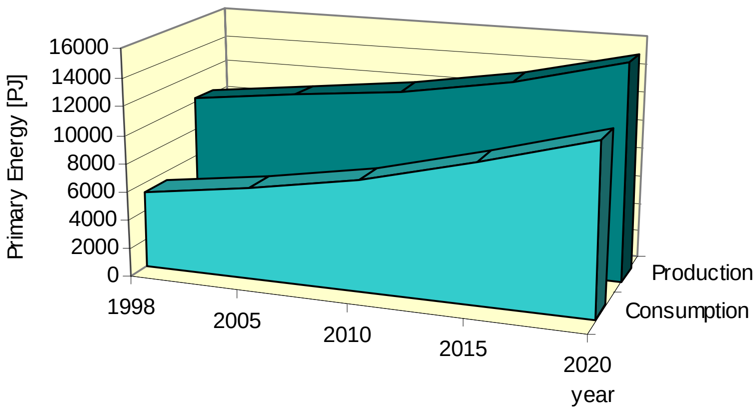
4 Results of different Energy and Emission Control Strategies for Iran

In this chapter the results of the EFOM-ENV model for adapted to develop energy and emission control strategies for Iran are evaluated and different scenarios compared.

4.1 Energy Supply and Emission control Strategies for Iran (Reference)

The development of primary energy consumption for the energy supply case is obtained by the application of the EFOM-ENV model. If no environmental restrictions are enforced and assuming that final energy consumption will increase according to the medium scenario of forecasts explained in chapter three, the growth of the primary energy consumption reflects the least-cost energy supply for Iran by 2020.

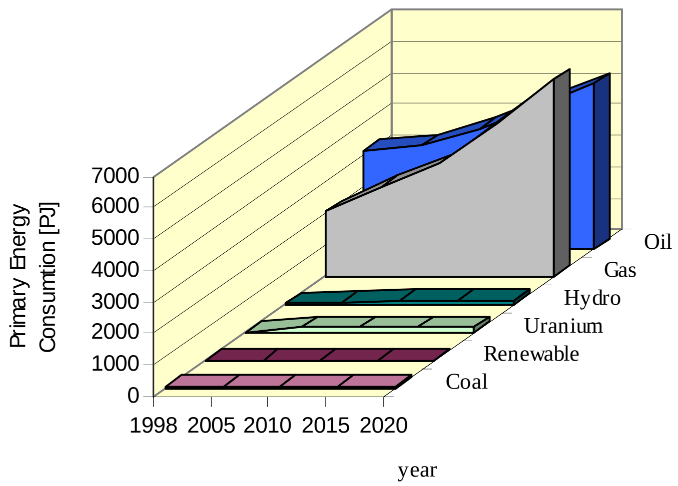
Figure 4-1: Development of Primary Energy Consumption and Production in the Reference Scenario



As Figure 4-1 shows, the total primary energy consumption will increase from about 5,000 PJ in 1998 to about 12,000 PJ in 2020, i.e. at an average annual growth rate of 3.8%. According to the results obtained from the model, in the same period the primary energy production will grow at a rate of 1.7% per year. Explicitly, it will increase from 10,000 PJ in 1998 to 15,000 PJ in 2020. This increase will be accompanied by structural changes. A part of the structural changes in the primary energy consumption can be attributed to the changes in the composition of the final energy consumption, i.e. substitution effects between the different primary energy forms, decreasing shares of oil and an increasing share of natural gas.

As Figure 4-2 shows, the contribution of oil and gas in the primary energy supply will increase drastically during the study period and the other energy carrier will not change considerably. The consumption of natural gas will rise from about 2,000 PJ to 7,200 PJ in 2020 with an average annual growth of 9.2%, while the consumption of oil will grow from 3,000 PJ to 5,200 in 2020 with an annual average growth of 2.4%. The share of gas in the total basket of the primary energy consumption will increase from 39% in 1998 to 52% in 2020, as the share of oil decreases from 59% to 44% .The switch from oil to gas as the major energy carrier is mainly caused by the comparatively cheap prices. Although the consumption of gas is more economical in the final sector, due to the lack of accessibility to the gas pipelines and the execution time of gas expansion projects, it is assumed that oil consumption will grow as in earlier periods but less than the gas consumption in the final sector.

Figure 4-2: Development of Primary Energy Consumption per Energy Carrier in the Reference Scenario



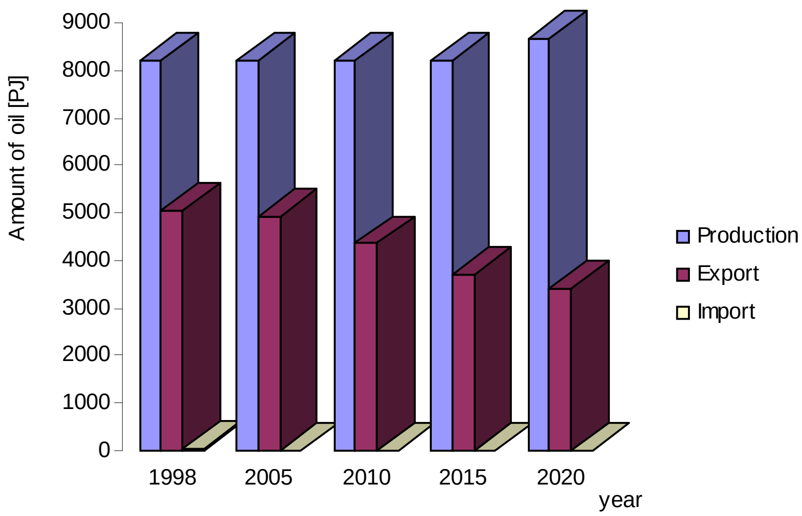
Among the other energy carriers, hydro will increase considerably by 2010 as compared to past years. This rise is due to about 10,000 MW hydroelectric power plants which are already under construction. The other renewable sources like solar energy, geothermal and wind contribute only a very small part to the primary energy consumption. The results of the model show them as an uneconomical option and only the renewable projects already under construction will contribute to the energy supply system.

As indicated by the results of the energy supply case, no additional nuclear power plants are considered as a cost-efficient supply option for Iran. Only 2,000 MW nuclear power plant will come into operation in 2005. The construction of this power plant has already begun.

Since the sole consumer of metallurgical coal is the steel industry, it is supposed that the industrial demand for coal will remain stable. The results of the model also show that coal plays an insignificant role in the production of energy in Iran as before. Steam coal, which is extracted from local mines, will be exported[59].

While the energy demand is growing, the level of oil exports and its products would decrease. The reduction of oil exports will have serious repercussions on the country's balance of payments position and the availability of foreign currency resources. Consequently, it can postpone the development of industrial progress. Figure 4-3 indicates the decrease of oil exports from about 5,000 PJ in 1998 to 3,400 PJ in 2020. An important consequence for the country, which has heavily oil-dependent economy, is a large deficit of foreign currency in the national budget.

Figure 4-3: Development of Oil Production and Export

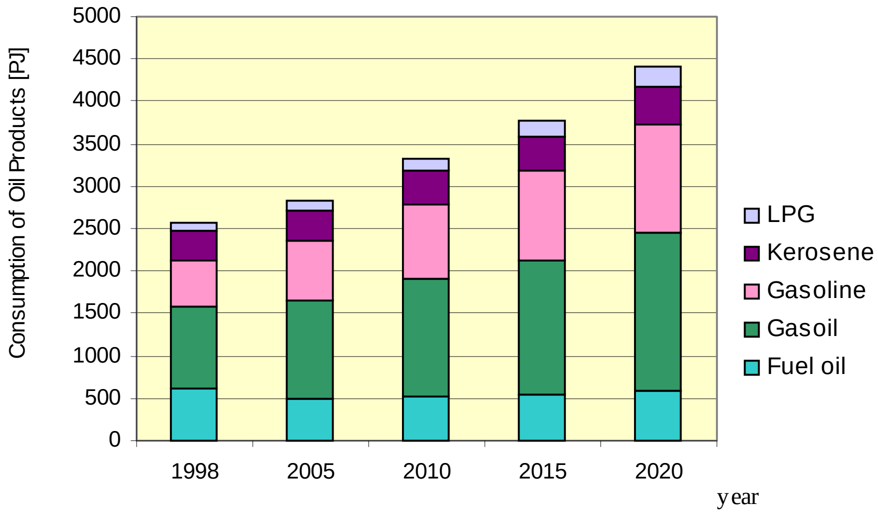


[59] The Iranian thermal steam coal is exported to Azerbaijan, Armenia, Turkey, Kuwait, Indian, Syria and some other countries [193].

Due to the insufficient production capacity of gasoline in the refineries and the increase in demand in the local market, about 50 PJ gasoline was imported in 1998. The results of the model indicate that the import of oil products remains an uneconomical solution.

With the projected decrease of the oil share in the final energy consumption and the substitution of oil by gas in the power generation sector, the consumption of oil products will increase more slowly than average. According to the model results, a shift in the consumption pattern can be expected. As Figure 4-4 indicates, the share of fuel oil in the total energy consumption will decrease from 24% in 1998 to 13% in 2020, while the share of gas oil and gasoline will increase in the same period.

Figure 4-4: Development of Oil Products Consumption in the Reference Scenario



This chart also shows the slight decrease in the consumption of kerosene in the residential/commercial sector. Kerosene accounted for about 14% of the total consumption of oil products in 1998 and this share will be reduced to 10% by 2020. The contribution of gas oil and LPG remain relatively constant in the Iranian market, about 41% and 4% respectively throughout the study period.

In order to adjust the supply to this growth and the consumption pattern, the structure of oil production or imports must be changed. For this purpose the structure of the oil refineries must be modified, i.e. the convention capacities must be expanded or new refineries established. As indicated by the results of the model, the additional demand for oil products will be satisfied by the expansion of new refineries. As Table 4-1 illustrates, the capacity of local refineries will increase from about 3,200 PJ in 1998 to 8,200 PJ in 2020. Besides the construction of new refineries, the extraction of crude oil must be increased. This requires expansion and discoveries in the oil fields as well as new extraction technologies. As a result, the export of crude oil will be drastically reduced and therefore it is recommended that oil products are exported instead of crude oil.

Table 4-1: Development of Refinery Capacity

	1998	2005	2010	2015	2020
Refinery capacity (PJ)	3,238	4,560	5,548	6,752	8,213

The consumption of natural gas will grow considerably in the study period, pushing its share up to more than 40% of the total energy consumption by 2020. As Table 4-2 shows, more than 40% of the total supplied gas was consumed by the electricity sector in 1998, 27% by industry and 15% by the residential/commercial sector. A rapid substitution of oil fuel by natural gas in the residential/commercial sector during the study period will change this balance, so that the share of the residential/commercial sector will reach 45% by 2020. While the share of two other sectors will be reduced between 1998-2020 compared to the reference year (1998).

The pattern of future primary energy consumption reflects the changes in the structure of the energy sector, especially with regard to development in the electricity sector. Electricity production will increase from about 25 TWh to 42 TWh in 2020, i.e. at an average annual rate of 2.4%.

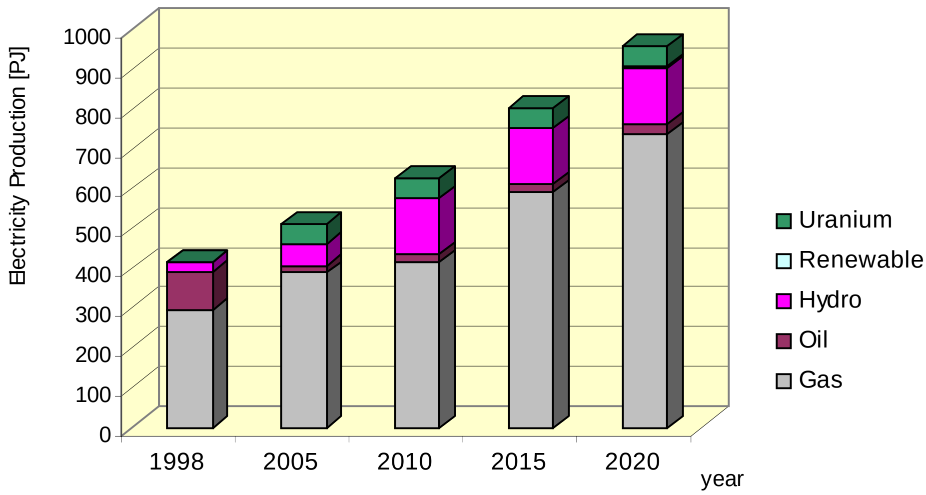
Table 4-2: The Share of Gas Consumption [%] in the Different Sectors

Sector	1998	2005	2010	2015	2020
Electricity	42	39	31	32	30
Industry	27	26	27	25	25
Residential/Commercial	31	36	42	42	45

Figure 4-5 shows the development of electricity production categorized by the fuel consumed. Natural gas will be the major contributor in this sector. The share of gas-fired power plants will increase, reaching from 71% in 1998 to about 77% of total electricity production in 2020. According to the results of the model, there will also be a decline in the share of oil-fired power plants from about 23% in 1998 to less than 3% in 2020. The 3% is related to those power plants, which are located far from gas pipelines in the southeast of Iran. It is assumed that they will use oil products for electricity generation during the study period.

Considering the 10,000 MW hydro power plants already under construction which will be put into operation from 2005 to 2010, the share of hydro in electricity production will reach from 6% in 1998 to 22% in 2010. This proportion will fall again to 15% by 2020 due to the construction of new gas combined cycle power plants.

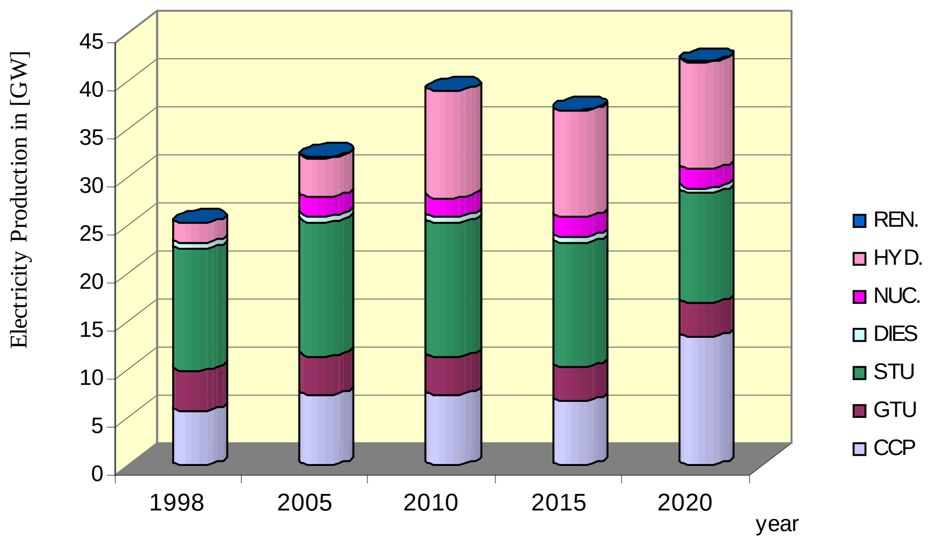
Figure 4-5: Development of Electricity Production by Energy Carrier



Electricity will be produced by the different power plant technologies as shown in Figure 4-6. According to the model results, an additional capacity of about 23,000 MW should be constructed in the study period. In 1998, the electricity production relied heavily on steam power plants. The contribution of steam turbines will be reduced from 50% in 1998 to 27% in 2020. Gas turbine power plants will play an insignificant role in the future electricity generation, so that their share will drop from 17% to 8% at the end of study period.

Among the electricity generation technologies which are projected to increase their shares in the surveyed period, the development of combined cycle power plants is highly recommended. By applying the model, the share of combined cycle power plants should increase to 32% of the total electricity production in 2020. The capacity of this technology will reach from 5,600 MW in 1998 to 14,000 MW in 2020. It must be noted that a 1,500 MW combined cycle power plant is already under construction.

Figure 4-6: The Share of Different Technologies in the Electricity Production



REN = Renewable
HYD = Hydroelectric
NUC = Nuclear
DIES = Diesel generator
STU = Steam turbine
GTU = Gas turbine
CCP = Combined Cycle Power plant

By 2020, the total capacity of hydropower stations will increase from about 2,000 MW to 11,000 MW. The additional capacities will be achieved by the projects under construction, while the results of the model do not recommend the construction of new hydroelectric power plant. After an increase in the share of hydroelectric power plants to 30% of the total electricity generation by 2015, its share will decrease again to 26% by 2020.

The contribution of other renewable energy in electricity generation will remain limited. Apart from 100 MW geothermal power generation and 8 MW wind turbines already under construction, the new renewable capacity will not add to the electricity sector. The industrial auto-producers (diesel generators) form 2% of the total electricity capacity and this share will remain constant during the period 1998-2020.

However, the use of industrial heat and power cogeneration for electricity and heat production would seem to be a cost-efficient alternative. It is assumed that the electricity supply through this technology can be implemented from 2010 due to the required infrastructure. The model results suggest the construction of a 1,300 MW cogeneration in 2010 and an increase to about 2,000 MW by 2020.

Figure 4-7: The Development of SO_2 Emissions in the Different Sectors

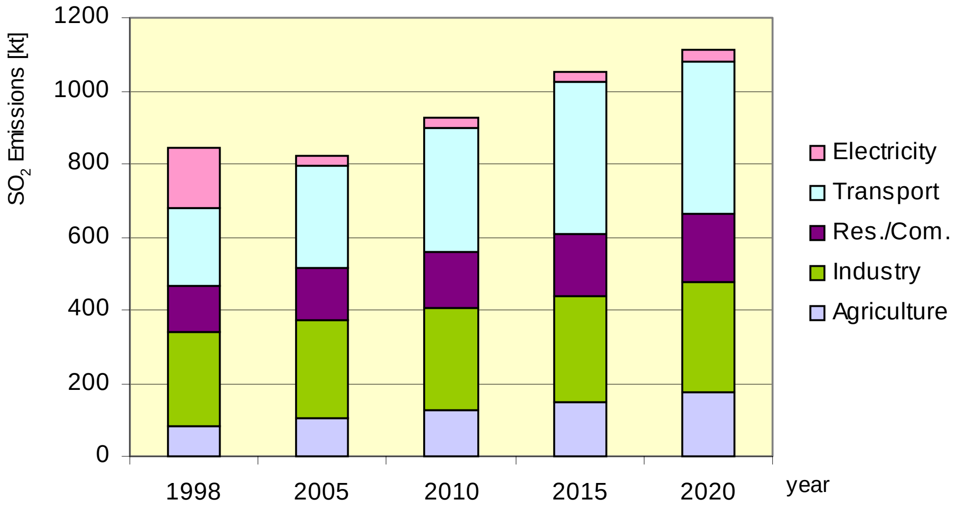


Figure 4-7 illustrates SO_2 emission source and their respective shares during the study period. The total SO_2 emissions are projected to increase from 956 kt in 1998 to about 1.4 Mt by 2020 with an average annual growth of 3.2%. The main sources of SO_2 emission have been identified as the transport sector, contributing 37% of the total SO_2 emissions in 2020. The sulphur content in the fuel (see Table 2-7) consumed by vehicles and high demand of gas oil in the transport sector generate high SO_2 pollution. In 1998, the transport sector consumed 11,957 m^3 gas oil while the electricity sector consumed 1,426 m^3.

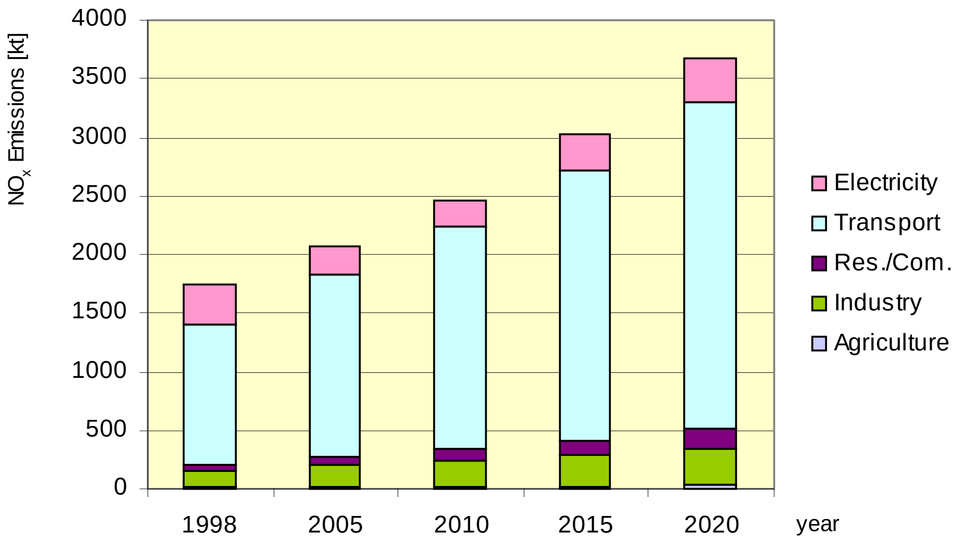
This chart also indicates the significant decrease of emissions from power plants. Emissions from the electricity sector accounted for about 20% of the total SO_2 emissions in 1998. The results of the model show that there will be a steep decline in SO_2 emissions of about 97% in the power plants. This is mainly due to substitution of oil by natural gas and the additional hydroelectric power plants under construction which will operate from 2005 onwards.

The contribution of industrial combustion sources to the total SO_2 emissions is also projected to decrease slightly from 31% in 1998 to 27% in 2020. This reduction results from the quick development of gas in this sector. The share of the residential/commercial sector will tend to remain relatively constant (about 16%) throughout the surveyed period.

The share of the agriculture sector in SO_2 emissions will increase from 10% in 1998 to 16% in 2020. Considering the development of mechanization and modernization in this sector, the increase of fuel consumption is expected. In 1998, the agriculture sector consumed 4,196 m^3 gas oil while the electricity sector consumed 1,426 m^3.

NO_x emissions will increase at a higher level than SO_2 emissions in Iran. Figure 4-8 shows, the impact of energy supply strategies in Iran on the development of NO_x pollution. The total NO_x emissions are forecasted to rise from 1.7 Mt in 1998 to about 3.7 Mt by 2020. As in many other countries, most of this increase arises from the transport sector which contributes 67% to the total NO_x emissions in 1998 and will contribute 76% in 2020. During the surveyed period, NO_x emissions from vehicle sources will increase as a percentage of the total NO_x emissions.

Figure 4-8: The Development of NO_x Emissions in the Different Sectors

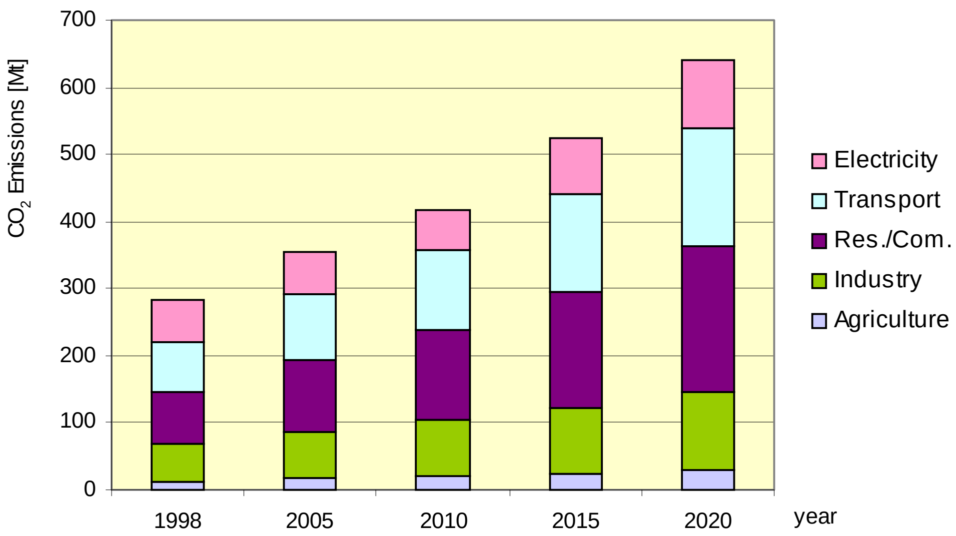


The substitution of oil by gas in the electricity, industrial and, residential/commercial sectors will cause an essential decrease in NO_x emissions. The share of the electricity sector in NO_x emissions will drop from 19% in 1998 to 5% in 2005 and afterwards will remain stable more or less up to 2020.

The contribution of the industrial and residential/commercial sectors to the total NO_x emissions is also projected to remain constant. The share of the industrial and residential/commercial sectors will be 9% and 4% respectively. The reason for this stability is mainly the penetration of natural gas into the residential/commercial and industrial energy market.

Figure 4-9 shows the expansion of CO_2 emissions from energy conversion over the study time period. CO_2 emissions will rise from 283 Mt to circa 640 Mt in 2020, which means an annual growth of 4%. This increase is about the same growth as in the final energy demand. The major contributors are the transport and residential/commercial sectors with a share of nearly 53% in 1998. From 2005 this proportion will increase to about 60%, a growth which will not change significantly throughout the planning period.

Figure 4-9: The Development of CO_2 Emissions in the Different Sectors



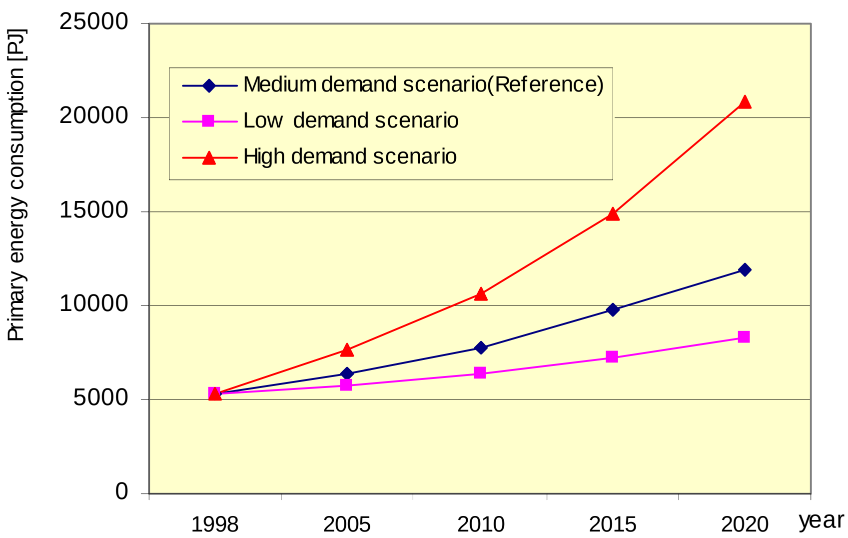
4.1.1 Effects of Different Energy Demand Scenarios

The increase of air pollution is mainly due to the projected development of energy demand. Since the future development of the energy demand is a major factor influencing the development of the energy supply system and has an impact on the environment, the effects of variation in the energy demand on the energy supply strategy have been analyzed.

As described in chapter three, three different energy demand scenarios have been defined: low scenario, medium scenario, and high scenario. In the medium demand scenario, called reference case, the final energy demand increases at an average annual rate of 4.3%.

Figure 4-10 shows the development of primary energy consumption determined by the model application during 1998-2020 for the different scenarios. The primary energy consumption increases at an average annual rate of 3.7% in the medium demand scenario. The growth of the primary energy consumption of fuel is 2.4% and 9.1% for oil and gas respectively.

Figure 4-10: The Development of Primary Energy Consumption for the Different Scenarios



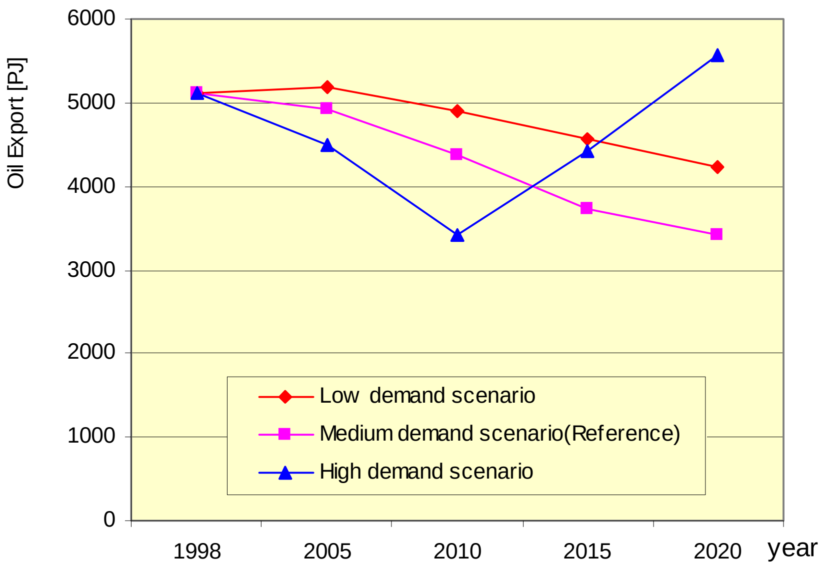
Looking at the primary energy consumption in the high demand scenario, the structural changes are greater than in the case of the medium energy demand growth. The consumption of oil and gas increases at a rate of 4.3% and 8.5% in the high demand scenario. The higher growth of oil compared to the medium demand scenario is due to the increase in the capacity of refineries which use mainly fuel oil and gas oil for their utilities and the development of the final oil demand in the residential /commercial and transport sectors.

The use of hydro energy, reaches a higher share in the low demand scenario than in the medium demand scenario. The share of hydro energy is about 20% of the total energy consumption in 2020 for the low demand scenario compared to its share (15%) in the medium demand scenario. This is due to the additional hydroelectric power plants already under construction which will operate completely in the two scenarios. The expansion of hydroelectric power plant covers the electricity deficit and reduces the share of fossil fuel in the low demand scenario.

Variations in the oil consumption have significant effects on the export of oil and consequently the revenue from sale of this energy carrier. When the final energy demand increases in the medium demand scenario, the consumption of oil will rise from 3,000 PJ in 1998 to 5,000 PJ in 2020. Considering the oil production ceiling for Iran on the basis of OPEC cooperation, the production of crude oil will remain on the same level as in 1998. According to the model results, the consumption of crude oil by the local refineries will be more than their production capacities in 2020. It is suggested that the overall production capacity will increase from 8,200 PJ to 8,600 PJ.

Figure 4-11 shows the oil export fall at an average of 1.8% annually i.e. from 5,000 PJ in 1998 to 3,400 PJ in 2020 in the medium demand scenario. This amount is 44% lower than the export of oil in the reference year (1998). In the low demand scenario, the production of crude oil remains stable and surplus oil is exported. Until 2005 the amount of oil exported will not change significantly and afterwards it will be reduced to 4,200 PJ by 2020, which means an annual average reduction of 1%.

Figure 4-11: The Development of Oil Exports



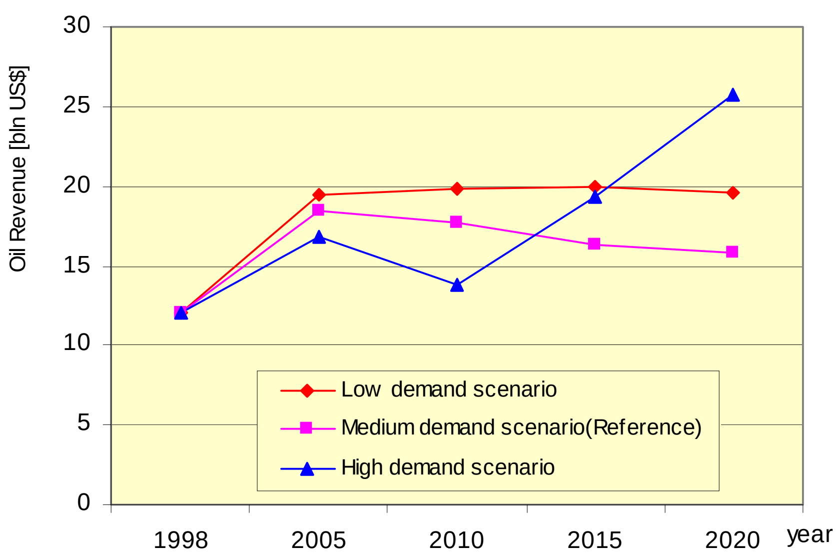
The most variations happen in the high demand scenario. The model results reveal that the extraction capacity of oil will rise from 8,000 PJ to 13,000 PJ in 2020. This difference between the scenarios is due to the contribution of export revenues from the sale of crude oil to the objective function. Until 2010, the capacity production of crude oil will cover the local demand of oil refineries and new investment in the oil sector are not considered in the model results. As the model cannot optimize the production structure of refineries, the increase in the gasoline demand will require the construction of new refineries in the model results.

It is expected that the rise in the capacity of refineries is more cost-efficient than the import of oil products. Therefore, after a rapid reduction in oil exports by 2010, these will increase again to about 5,600 PJ in 2020.

Besides the negative effects on the environment and reduction of oil revenue, the increase of oil consumption in the Iranian energy market brings difficulties in the world oil market (see Figure 1-2) and consequently will result in an increase of the oil prices. As the oil revenue plays a major role in the Iranian economy, its variation is shown in Figure 4-12.

Although oil exports will be reduced in the medium demand scenario, the oil revenue is expected to rise until 2005 due to the increased oil prices. From 2005 onwards, the oil revenues will decline by 0.8% compared to the revenue in this year but it will be higher than the reference year (1998). In the low demand scenario, the reduction of oil production, in addition to the growth of oil price, keeps the revenue at a steady level. According to the variations in oil exports, the oil revenue will vary in the high demand scenario differently compared the two other demand scenarios. As the oil export trend, the major variations in the oil revenue ensue in the high demand scenario. In the first period the oil revenue will grow, then there will be a rapid reduction and in 2010 an increase will ensue due to the expansion of oil extraction.

Figure 4-12: The Development of Oil Revenues

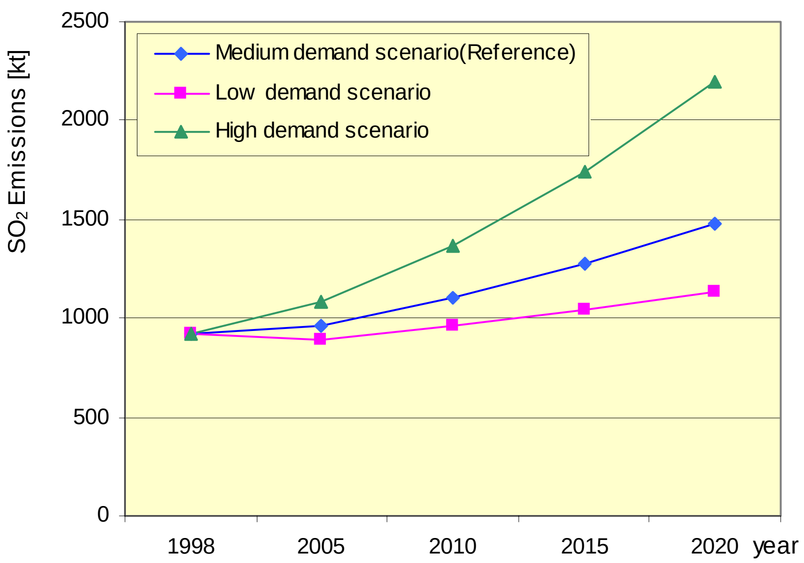


The effects of a variation in the energy demand on the development of SO_2 emissions are shown in Figure 4-13. For all demand scenarios, the profile of SO_2 emissions reveals a steady increase between 1998 and 2020. SO_2 emissions will increase practically according to the final energy demand. They will be lower in the low demand scenario than in the medium demand scenario and higher in the high demand scenario. However, this variation is not proportional to the change of the energy demand throughout the study period.

In the low demand scenario, SO_2 emissions are expected to increase to nearly 1.1 Mt by 2020. This is 24% lower than in the medium scenario, while the primary energy consumption will be more than 31% lower in this year. The difference is due to the higher consumption of clean fuel (gas instead of oil) in the end-use sector and the new power plants will be operated mainly by gas. Between 1998-2005 the amount of SO_2 emissions will remain stable more and less and from 2005 onwards, SO_2 emissions will increase at a slow rate.

Looking at the electricity generation in the low demand scenario, the required capacities to meet the additional demand by 2020 will be met mainly by the hydroelectric power plants already under construction, and these will operate from 2005 onwards. Additional nuclear capacities will also come into operation in 2005. This means that the technological structure of the electricity sector is expected to change in favor of the use of cleaner fuels. Therefore in the medium scenario, the growth of SO_2 emissions will be lower than the growth of primary energy consumption.

Figure 4-13: The Growth of SO_2 Emissions for the Different Demand Scenarios

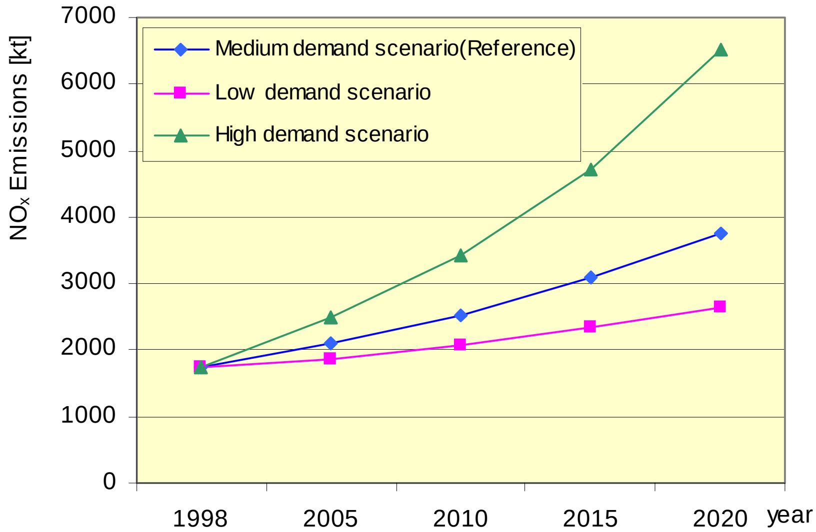


Consequently in the high demand scenario, the difference between the amounts of SO_2 emissions from those sources in the medium scenario will be lower than the difference in the primary energy consumption. SO_2 emissions are 48% higher than in the medium demand scenario, while the primary energy consumption in the high demand scenario will be 75% higher than the consumption in the medium demand scenario 2020.

If the high demand scenario is applied, the shift to the consumption of cleaner fuels with respect to SO_2 emissions will be even more significant than in the medium demand scenario. In the final energy consumption, it is assumed that the gas expansion will follow previous trends but with a slow increase. This is due to the limited financial and skilled human resource.

The projection of NO_x emissions indicates an increase. Figure 4-14 shows that NO_x emissions will develop proportionally to the energy demand. It shows also an almost identical behavior in the three demand scenarios until 2020. Contrary to SO_2, NO_x emissions will increase at about the same rate in primary energy consumption. This is due to the different emission characteristics of the fuels relative to SO_2 and NO_x emissions.

Figure 4-14: The Growth of NO_x Emissions for the Different Demand Scenarios



In the medium demand scenario, NO_x emissions will rise from 1,700 kt in 1998 to 3700 kt in 2020. It seems that they will grow similarly to the primary energy consumption at a rate of 3.4% annually. In the low demand scenario, NO_x emissions will increase to 2,600 kt and their amounts will be 30% lower than emissions in the medium demand scenario. For the high demand scenario, the trend of NO_x emissions is the same as for the other two scenarios, but on a considerably higher level. In the high demand scenario, NO_x emissions will increase to 6,500 kt, nearly 70% higher than NO_x emissions in the medium demand scenario.

The development of NO_x emissions depends on the technology mix, which is added to the existing energy supply structure to meet the additional requirements. Apart from the structural changes in the energy utilization sectors, reflected by the final energy demand, the electricity sector is the second important emitter in this respect.

Figure 4-15: The Growth of CO_2 Emissions for the Different Demand Scenarios

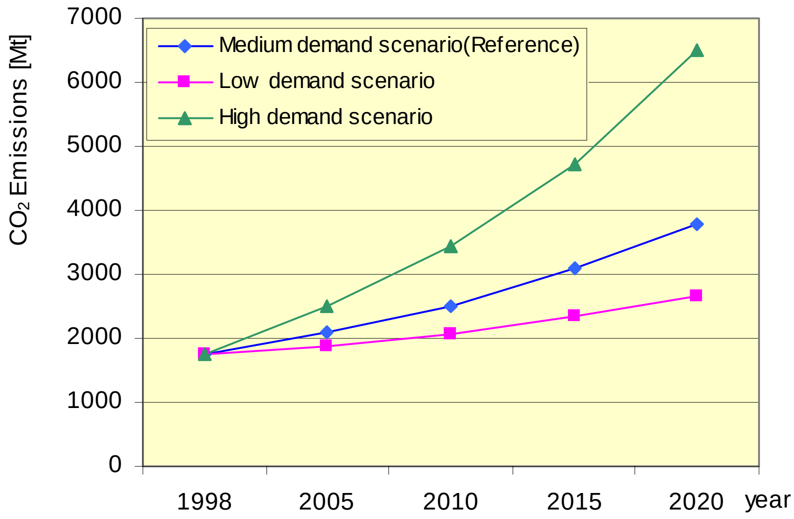


Figure 4-15 indicates the development of CO_2 emissions during the surveyed period. For all three demand-scenarios, the model results show the same trend for CO_2 emissions. In the medium demand scenario, CO_2 emissions will increase from 301 Mt in 1998 to 690 Mt in 2020. CO_2 emissions grow at a rate of 3.9% annually which would seem to be higher than the NO_x emissions growth rate. In the low demand scenario, CO_2 emissions will rise to 481 Mt in 2020. In the same period they will increase to 1232 Mt in the high demand scenario, which is three times more than the amounts in the low demand scenario. The development in CO_2 emissions is comparable to the growth of final energy consumption.

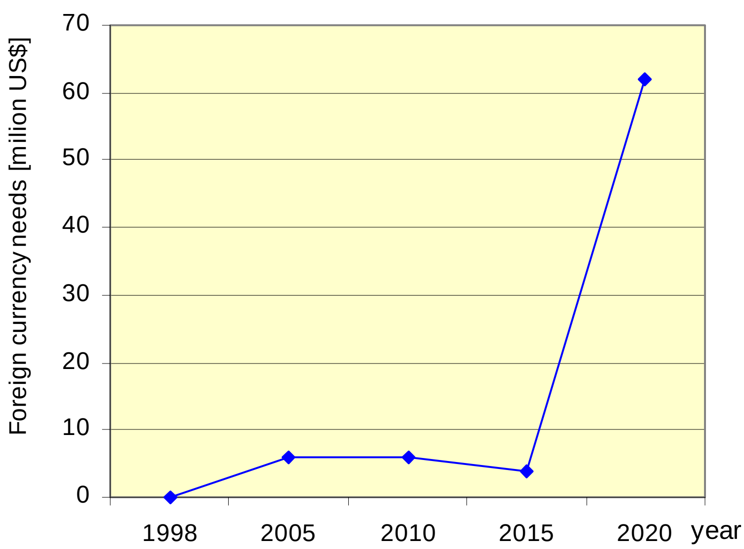
4.1.2 Variation of the Exchange Rate of US$

One of the most important factors for the evaluation of model results is the exchange rate of foreign currency. It has a major influence on the model results especially for investment in new utilities. The impact of three exchange rates on the development of energy and emission control strategies has been analyzed. In the reference case, one Dollar should to be equal to 1,750 Rials. The model results for the exchange rate of 3,000 Rials US$ for do not differ considerably to those in the reference dollar case. On the other hand, the model reacts against the highest exchange rate i.e. when one US$ is equal to 8,500 Rials.

As shown in Figure 4-16, these effects can be seen in the foreign currency costs. An actual increase in the US$ exchange rate will increase most energy investment costs. This is due to the fact that most industrial plant and equipment must be imported. It seems that when the value of the US$ increases, the model results recommend those technologies or energy carriers, which involve less foreign currency. This is due to the negative contribution of export revenues from energy to the objective function.

Until 2015 the volume of foreign currency will remain more and less constant. Considering the model results, most foreign currency will be invested in the electricity and oil sectors. Since considerable investments are not taken into account in the oil sector, the greatest reduction in the volume of foreign currency will be derived from the electricity sector in 2020. In the reference dollar scenario, the new investment will be put into the combined cycle power plants, but in the high dollar scenario gas turbine power plants are recommended. As the construction of gas turbine power plants require less foreign currency than the combined cycle power plants, the results seem to be cost-efficient.

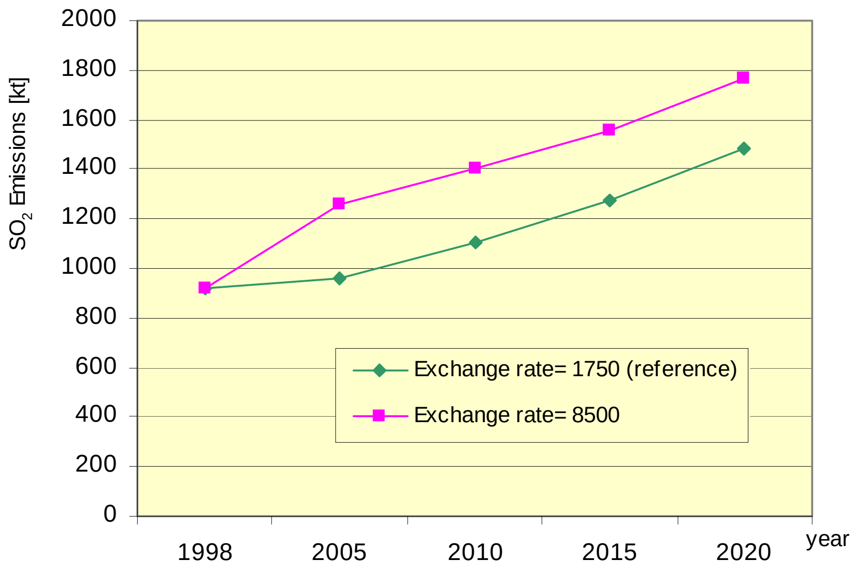
Figure 4-16: The Changes in the Volume of Foreign Currency Needs



With the variations in the foreign exchange rate, the mix of technologies changes resulting in different levels of emissions. As shown in Figure 4-17, SO_2 emissions develop at a higher level than in the reference dollar case. They reach from 920 kt in 1998 to 1,700 kt in 2020, i.e. about 17% more than the reference dollar case in the surveyed period. The additional SO_2 emissions arise from the structural changes in the electricity sector. During the study period, the consumption of natural gas will be lower than fuel oil in the electricity sector.

NO_x emissions grow at an annual average rate of 3.9% higher than the growth of SO_2 emissions. In the high dollar scenario, NO_x emissions will increase from 1700 kt in 1998 to 4040 kt in 2020. The above reasons apply to the growth of NO_x and CO_2 emissions. The change in CO_2 emissions is projected to be the lowest of the three emissions. CO_2 emissions will increase at an annual average rate of 1.4%, amounting to 12,77 Mt in 2020.

Figure 4-17: The Variation in SO_2 Emissions for the Different Exchange Rates



4.1.3 Emission Reduction Strategies

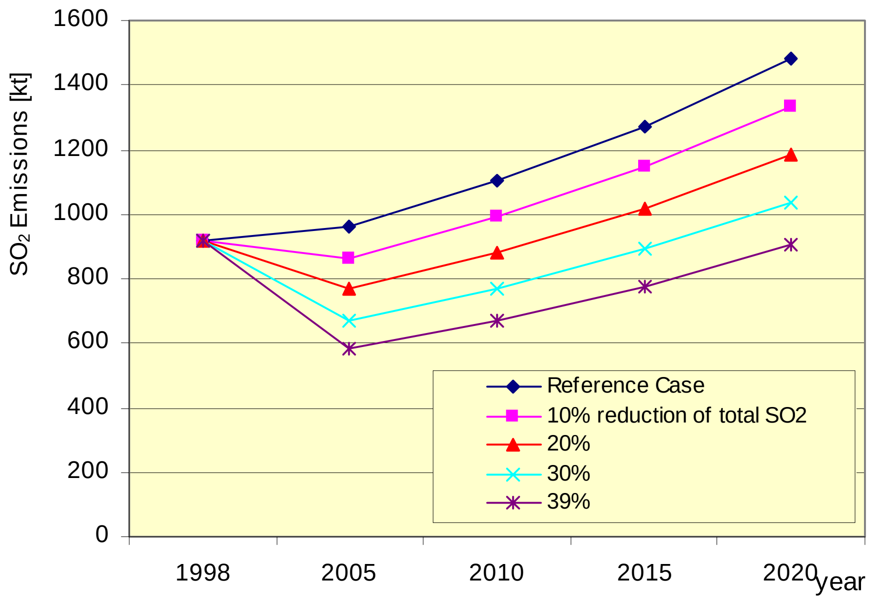
As expected, SO_2, NO_x, and CO_2 emissions will increase during the study period. For integration of environmental aspect in the model, it is necessary to determine long-term emission reduction strategies. Using a cost-efficient emission reduction provides a framework for the ranking of emission control measures according to their cost-efficiency, and the assessment of the cost-efficiency of control strategies.

The model application results in a least-cost mix of emission control measures for the different target levels of emission reduction. The economic implications of emission reduction strategies can be summarized by cost-functions, representing the relation between the amounts of emission reduction and emission reduction costs.

- ***SO_2 Emission Reduction***

As described in chapter one, there are no significant control strategies and policies for emission reduction in Iran. The question is, by how much these emissions can be reduced. Therefore, a constraint has been put on the maximum SO_2 emissions level over the study period to achieve a significant reduction. An annual reduction level of 10%-40% of SO_2 emissions has been included in the medium demand scenario. The maximum possible reduction of SO_2 emissions has been determined at about 39% of total SO_2 emissions during the study period.

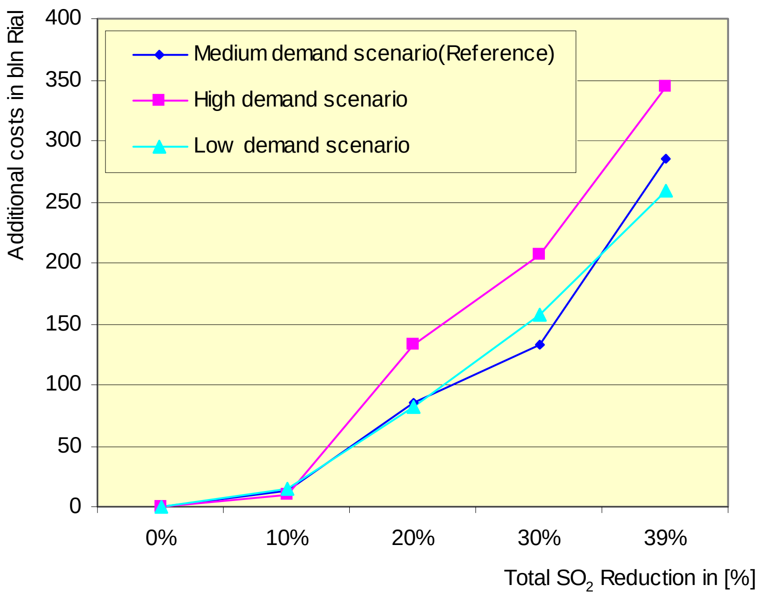
Figure 4-18: SO_2 Emissions for the Different Percent Reduction Levels



As indicated in Figure 4-18, in the most cases, the amount of SO_2 emissions are higher than the amount of SO_2 emissions in 1998. With a level of 39% reduction, the SO_2 emissions will remain at a lower level than the amount of SO_2 emissions in the energy supply scenario. Considering that oil substitution by gas will be completely achieved in the final demand sector, a reduction of more than 39% of total SO_2 emissions during the study period is impossible. The total amounts of SO_2 emissions will reach 3.8 Mt during the surveyed period. For the high demand scenario, the maximum achievable reduction is 39%. This corresponds to SO_2 emissions of about 4.8 Mt during 1998-2020, 20% higher than the energy supply case in the same period. If the low demand scenario applies, the maximum achievable SO_2 reduction will also be about 39% of the total emissions, which is about 700 kt in 2020, i.e. 75%, as opposed to the energy supply case in 1998.

To achieve a maximum SO_2 reduction, additional expenditure will be required (i.e. an increase in the objective function value of the model compared to the energy supply case). The variation in the cost function for the reduction of SO_2 emissions is shown in Figure 4-19. It shows the discounted additional energy system costs required to achieve varying SO_2 target values for the medium and low demand scenarios. Each point on the cost function corresponds to a least-cost mix of emission control measures, as determined by the model application, to achieve the respective SO_2 target value. The resulting additional costs can be interpreted as a lower limit for the SO_2 abatement costs to achieve a specific overall SO_2 target value.

Figure 4-19: Marginal Cost of Total SO_2 Emission Reduction Compared with 1998



That means that under the assumptions considered in this study, it is possible to achieve a long-term SO_2 reduction of 39% compared to 1998. To achieve this reduction target, about 517 billion Rials must be invested in the medium demand scenario. This corresponds to 1% of the total energy costs during the study period in the medium demand scenario. In the low demand scenario, the respective costs will be about 513 billion Rials, so that the total costs are 0.6% higher than in the low demand energy supply scenario.

Table 4-3 shows the additional foreign currency required to reach the maximum SO_2 emissions reduction level for the three demand scenarios. A 39% decrease in SO_2 emissions will require additional expenditure in the order of US$258 million in the medium scenario. However the improvement is small for a reduction of up to about 10% in SO_2 emissions compared to 1988. The additional costs for a 39% reduction in SO_2 emissions amount to US$230 and US$375 million respectively in the low and high demand scenarios. It means that the marginal abatement costs will rise with the increasing SO_2 reduction levels.

Table 4-3: The increase in Foreign Currency needs for Maximum SO_2 Reduction (mln US$)

Scenario	2005	2010	2015	2020
Medium demand scenario (Reference)	56	61	67	74
High demand scenario	60	70	85	160
Low demand scenario	54	56	58	62

For a maximum reduction in SO_2 emissions i.e. 39%, the volume of foreign currency in the cost function will increase by 7% at the most as opposed to the energy supply case, due to the installation of emission control devices. From the total foreign currency about 5% concerns the electricity sector, 3% will be spent on the expansion of gas and 92% on the installation of emission reduction technologies in the industrial combustion system. The volume of foreign currency in the cost function will rise 4% and 11% respectively in the low and high demand scenarios compared to the basis scenario. The high increase in the volume of foreign currency in the high demand scenario is due to the costs of the SO_2 emission reduction technology in the industrial sector. In the low demand scenario, the model results will assign foreign currency in the proportion of 7%, 4% and 89% respectively to the electricity, gas and industry sectors.

As mentioned above, each point on the cost function shown in Figure 4-19 represents a least cost mix of emission control measures. Consequently, the emission control measures can be ranked depending on the emission reduction level. A lower level of SO_2 emissions reduction in 2020 versus the reference year can be achieved by substituting high sulphur fuels with low sulphur fuels or oil fuel with gas. Fuel switching is the most cost efficient emission control measure for less stringent emission reduction targets. This concerns mainly the substitution of fuel oil by natural gas in the refineries.

As described above, from a practical point of view a complete substitution of oil by gas cannot be taken into account but additional fuel switching is considered through gradual growth in the final demand. According to the results of the energy supply case, the fuel will be substituted by gas in most oil-fired power plants of the energy conversion sector. Only the refineries will use oil products. According to the results of the model for a SO_2 emission reduction level of 10%, the fuel in all refineries will be substituted by gas.

Table 4-4: Consumption of Oil and Gas (PJ)

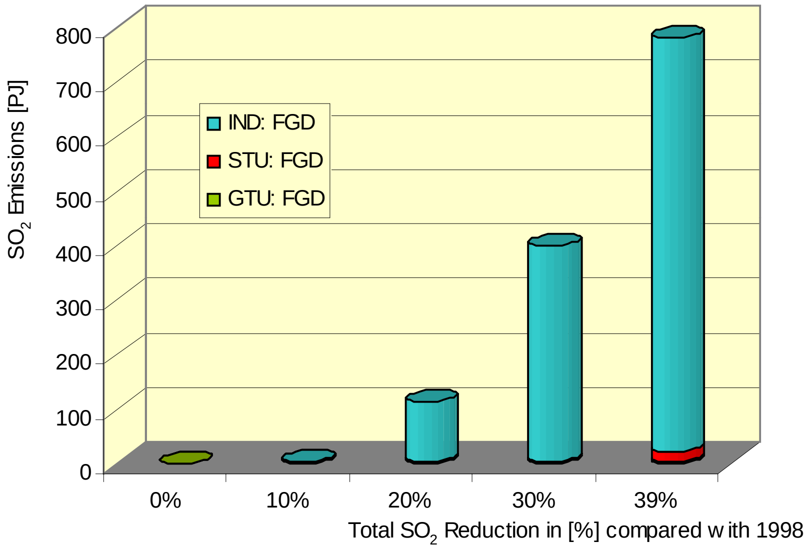
	1998	2005	2010	2015	2020
Gas in the energy supply case	2085	2857	3602	4915	6291
Gas in the SO_2 reduction case	2085	3042	3843	5223	6682
Oil in the energy supply case	3143	3298	3853	4523	5275
Oil in the SO_2 reduction case	3143	3105	3595	4177	4898

Use of fuel substitution in the primary energy consumption comprises mostly the substitution of oil by natural gas. Table 4-4 shows the composition of oil and gas in the primary energy consumption for the medium energy demand scenario and the maximum levels of SO_2 reduction in the environment case. To increase the SO_2 reduction target level, the share of natural gas increases mainly due to the fuel switching in the oil sector. Natural gas will grow 6% more than in the energy supply case, while the consumption of oil will be reduced by about 7% in the same period.

In the group of technology substitution measures, the future demand of electricity will be met by the natural gas-fired combined cycle power plants in the cost-efficient energy supply model. With increasing SO_2 reduction targets, the capacity of flue gas desulphurization facilities will be expanded but due to the high fuel substitution in the electricity and oil sector, this capacity is not considerable compared to the total SO_2 abatement measures.

Figure 4-20 demonstrates the contribution of the different emission control measures for the different levels of SO_2 emission reduction. If the SO_2 emissions are to be reduced to a level of 10%, besides fuel substitution in the refineries, flue gas desulphurization is recommended for those gas turbine power plants which have no access to gas pipelines. The measures taken in the power plants are most cost-efficient, achieving a high SO_2 emission reduction for the lower reduction levels.

Figure 4-20: Ranking of the SO_2 Abatement Measures



IND: FGD = Flue Gas Desulphurization for Industries
STU: FGD = Flue Gas Desulphurization for Steam Turbine Power plants
GTU: FGD = Flue Gas Desulphurization for Gas Turbine Power Plants

For 20% reduction of total SO_2 emission, flue gas desulphurization is recommended for industrial heating boilers. Flue gas desulphurization is a cost-efficient measure for a 95% reduction of SO_2 in industrial boilers. The maximum reduction of SO_2 will be obtained in the industrial sector where the restriction of fuel substitution has been assumed. For reduction targets of 30%, the set of SO_2 emission reduction measures is almost the same, even on different operation levels in industrial boilers. To reach a maximum SO_2 reduction i.e. 39%, besides increasing flue gas desulphurization for industrial heating boilers, the wet limestone process is suggested for steam turbine power plants. SO_2 emissions will remain essentially constant in the transport sector. The model projected a slim reduction of SO_2 emissions in the industrial and residential/commercial sectors due to an increasing demand for gas for heating purpose.

- ***NO_x Emission Reduction***

To achieve a maximum NO_x emission reduction, a reduction level of 10 to 61% has been calculated for the medium demand scenario during 1998-2020. The maximum achievable reduction of NO_x emissions during the study period is determined at about 61% per annum, which is much higher than the rate for SO_2 emissions. This is mainly due to the reduction of NO_x emissions arise from combustion of natural gas. Figure 1-1 illustrates, from the level of 50% reduction, the NO_x emissions will be lower than emissions in the reference case in 1998. In the maximum reduction level, the total NO_x emissions will reach 6 Mt during the surveyed period, which is 57% higher than SO_2 emissions in the same case.

By applying the high energy demand scenario, the maximum achievable reduction is 61%. The total NO_x emissions will be reduced by about 8.1 Mt during the study period, which is 34% higher than the reference case in the same period. For the low demand scenario, the maximum achievable NO_x reduction will also be about 61% of the total emissions. These will reach about one Mt in 2020, which is 58% NO_x reduction as opposed to the basis scenario in 1998.

Figure 4-21: NO_x Emissions for the Different Percent Reduction Levels

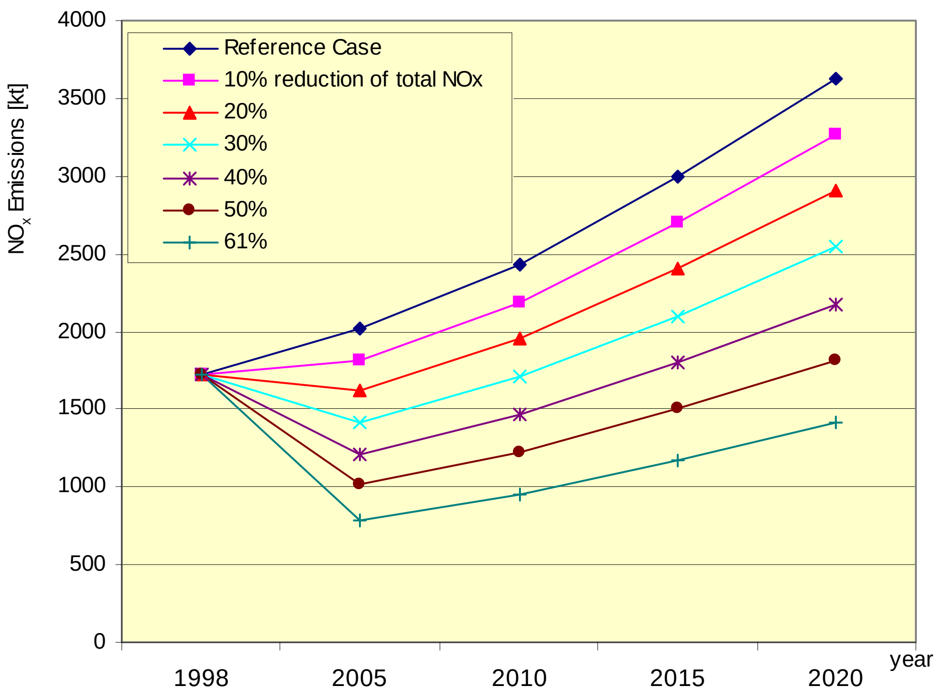


Figure 4-22 shows the additional discounted costs for the different levels of NO_x reduction. For up to 50% decrease of NO_x emissions, abatement costs will grow proportionally to reduction. To reach a maximum level of NO_x reduction, these costs increase to a large extent due to the variations in the abatement technologies. For a maximum NO_x reduction, about 13,300 billion Rials must be invested in the medium demand scenario. In the low demand scenario, the respective investment will be about 11,600 billion Rials, i.e. the total costs are 13% lower than in the medium demand scenario. To obtain a maximum reduction in the high demand scenario, 13,300 billion Rials must be spent which is 37% more than in reference case.

Figure 4-22: Marginal Cost of Total NO_x Emission Reduction Compared with 1998

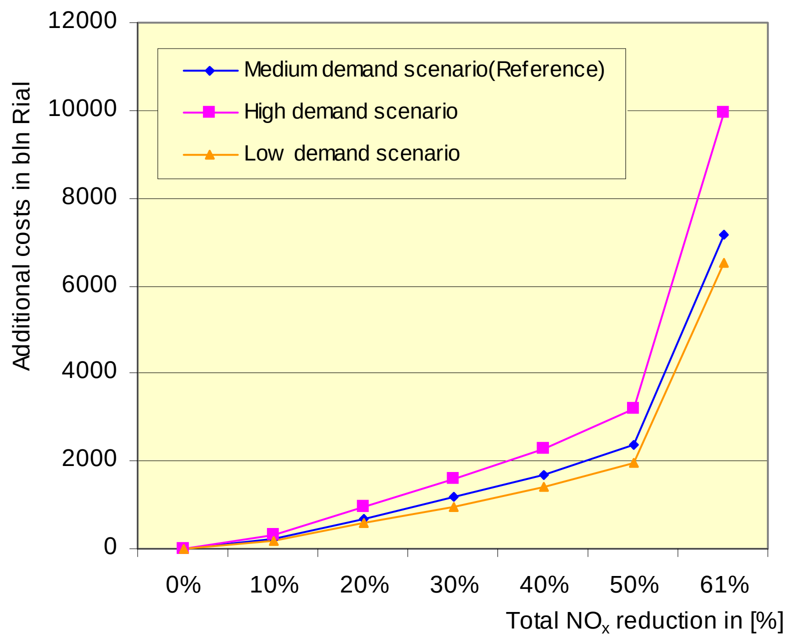
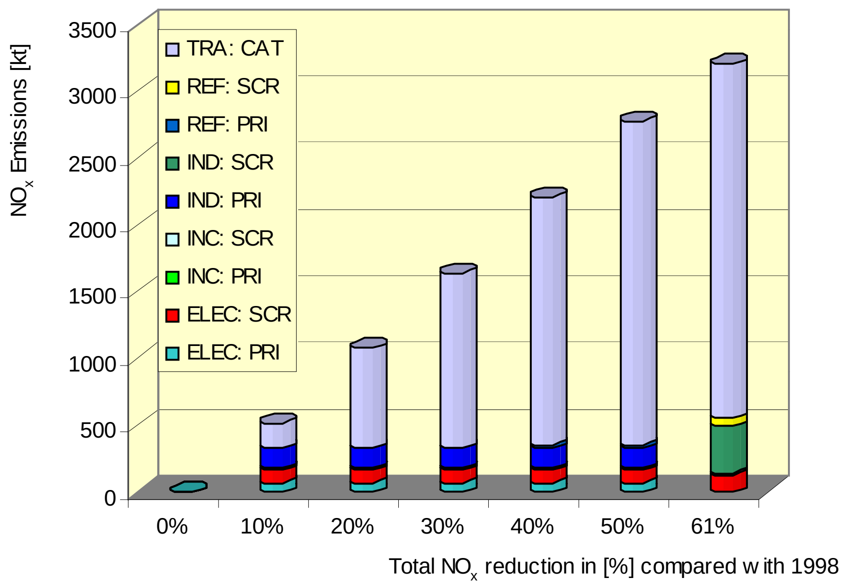


Table 4-5: The Increase of Foreign Currency for Max. NO_x Emission Reduction (mln US$)

Scenario	2005	2010	2015	2020
Medium demand scenario (Reference)	929	1585	1822	2302
High demand scenario	1131	1871	2893	4411
Low demand scenario	848	1401	1566	1769

Table 4-5 shows the additional foreign currency needed to obtain a maximum reduction of NO_x emissions for the three demand scenarios. For a maximum reduction of NO_x emissions, additional costs in the order of US$6638 million are required in the medium scenario. These additional costs amount to US$5584 and US$10306 million for a 61% reduction of NO_x emissions respectively in the low and high scenario. For a maximum NO_x reduction, the accumulated foreign investment expenses increase more than 2.8 times as opposed to the reference case. From the total emission reduction costs, the transport sector with a share of 64% will contribute the largest part to foreign currency costs, followed by the electricity sector, which will account for about 40% of the total foreign currency costs. Seven percent will be assigned for the installation of emission reduction technologies in the industrial combustion systems and finally 4% will be spent in the oil sector for NO_x emission reduction.

Figure 4-23: Ranking of the NO_x Abatement Measures



ELEC = Electricity Sector	TRA = Transport
IND = Industry Sector	PRI = Flue Gas Desulphurization
INC = Industrial Cogeneration	SCR = Selective Catalytic Reduction
REF = Refinary	CAT = Primary NO_x Reduction Technology

Figure 4-23 shows the role of different emission control measures in the total NO_x reduction compared to the reference case in 2020. Contrary to the SO_2 emission reduction, fuel switching is not among the most cost-efficient measures for the reduction of NO_x emissions since the properties of the different fuels forming NO_x do not vary as much as with respect to SO_2 formation. Contrary to SO_2, NO_x formation depends greatly on the combustion process rather than on the fuel properties. For a NO_x emission reduction level lower than 0.1%, the fuel oil in all refineries will be substituted with gas oil by the model results. The low reduction is mainly due to the fact that the reduction of NO_x emissions is potentially low using substitution measures.

The most efficient control measures to achieve comparatively moderate NO_x reductions are primary measures i.e. combustion control techniques. For the existing power plants and the industrial sector, the installation of primary processes are recommended when considering the model results. This option is a cost-efficient measure, in so far as a reduction target of 50% is aimed for.

The emission control measures for the transport sector have also been recommended in the model. According to the model results, the installation of catalytic converters in vehicles contributes greatly to overall NO_x reduction. In all reduction levels, this measure has the greatest share in NO_x emission reduction. At a maximum reduction level, it will contribute with a share of 82% to overall NO_x emissions, even if all fuels were controlled catalytically. The major reason for the high NO_x reduction rates is the projected growth of the transport sector.

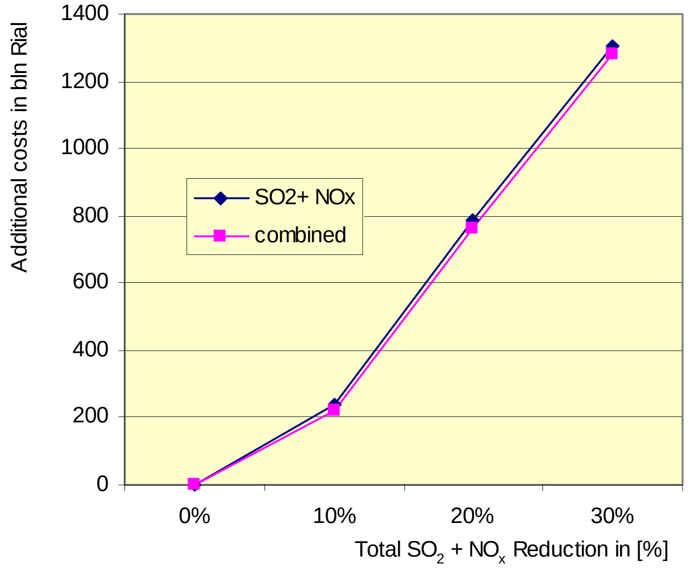
If the NO_x emissions are to be reduced further to a level of 40%, the set of NO_x emission reduction measures is almost the same, even on different operating levels in the transport sector. A primary measure is advised for the input of refineries. With increasing NO_x reduction targets to a maximum level (61% reduction), the capacity of SCR facilities will be expanded in the electricity, oil, and industrial sectors and primary measures will be eliminated.

- ***Combined Reduction of NO_x and SO_2 Emissions***

If the reduction of both NO_x and SO_2 emissions are intended, the same approach as applied for the separate reduction of air pollutants, can be used. By setting restrictions on the total emissions of both pollutants, cost-efficient strategies can be developed for every combination of SO_2 and NO_x target emission values.

The effects of such combined reduction strategies on the energy system costs are shown in Figure 4-24. When reducing SO_2 and NO_x emissions simultaneously, the measures taken to decrease one pollutant may reduce the emission of the other pollutant as well. Consequently, cost-efficient strategies for the reduction of both SO_2 and NO_x emission control can be developed by simply adding the result from the separate reduction of both pollutants, but they have to be determined explicitly for each set of SO_2 and NO_x reduction targets.

Figure 4-24: Total Marginal Abatement Costs for the Combined Reduction of NO_x and SO_2 Emissions Compared with 1998



As a result, it is expected that the control costs of a combined reduction of SO_2 and NO_x emissions are lower than the sum of the costs of the separate reduction of the pollutants. Both cost functions represent the emission control costs for the different SO_2 and NO_x reduction levels. The maximum level is considered to be 30% for SO_2 and NO_x emissions. The lower function shows the control costs resulting from the simultaneous restriction of both pollutants, while the upper function has been determined by adding the control costs of the separate reduction of NO_x to the respective costs for the separate SO_2 reduction.

Since the substitution of oil by gas in most power generations is recommended in the results of the energy supply scenario, the potential of fuel switching and technology substitution, which can reduce both emissions simultaneously, will remain at a low level. Therefore, a small difference is expected between the two functions in the combined reduction measure of SO_2 and NO_x. This holds true for all levels of SO_2 and NO_x reduction. Compared to a separate reduction of SO_2 and NO_x emissions, emission control cost savings in the order of 2.2% can be achieved by a combined strategy in Iran.

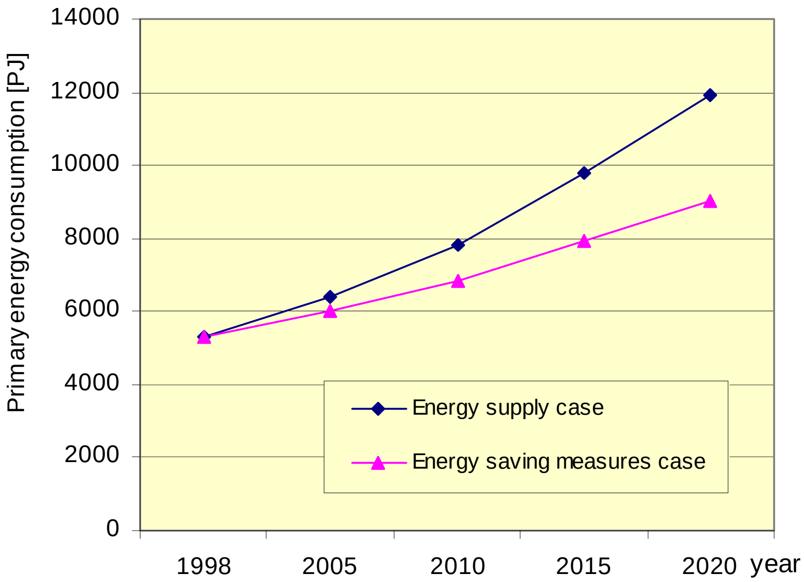
- ***CO_2 Emission Reduction***

In connection with the advanced awareness of greenhouse gases, CO_2 reduction has also been considered in the model. Since no specific CO_2 removal technologies have been introduced into the model, the possibilities for reducing CO_2 emissions are mainly due to fuel substitution and technology switching options. As the substitution of oil by gas will be completed for the conversion sector in the energy supply scenario, it will remain a low potential for the reduction of CO_2 emissions by this method.

The technology options for a high CO_2 emission reduction are high efficiency energy conversion technologies, like the combined cycle power plants using gas, gas turbines for combined power and heat production, and renewable energy technologies, mainly the use of all hydro power potential, wind turbines, solar power generation and geothermal energy. These options also cause additional costs for CO_2 emission reduction especially when applying renewable energy technologies.

Energy efficiency improvements are able to cut CO_2 emissions in an economic way. As described in chapter one, in the final sector many untapped potentials exist to increase energy efficiency and to reduce CO_2 emissions. Policies that promote energy efficiency are intended to reduce energy use without adversely affecting the level of energy services. The total energy saving potentials are supposed to be 6%, 20% and 30% during 1998-2020 respectively for the conversion, industrial and residential/commercial sectors. Considering energy conservation in all sectors, the primary energy consumption will change as shown in Figure 4-25.

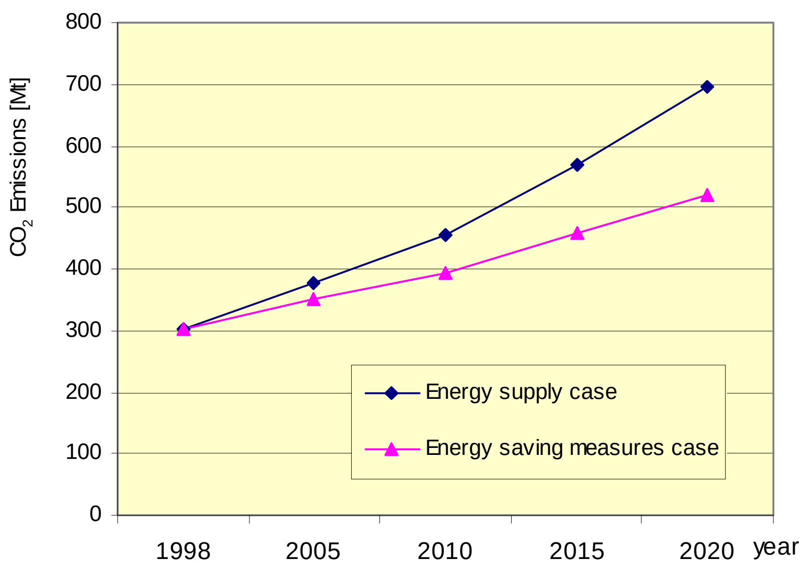
Figure 4-25: Reduction in the Primary Energy Consumption through Energy Saving Measures



If the energy saving measures are put into effect, the total primary energy consumption will fall by 9000 PJ, i.e. 15% reduction during the study period compared to the energy supply case. The reduction has positive effects on the investment costs so that the total costs will decrease from 44,000 billion Rials to 41,000 billion Rials. The model results also reveal that the power plants already under construction will come into operation and new investment will not be necessary in this area. Oil exports will increase by 20% in 2020 compared to the volume in the energy supply case.

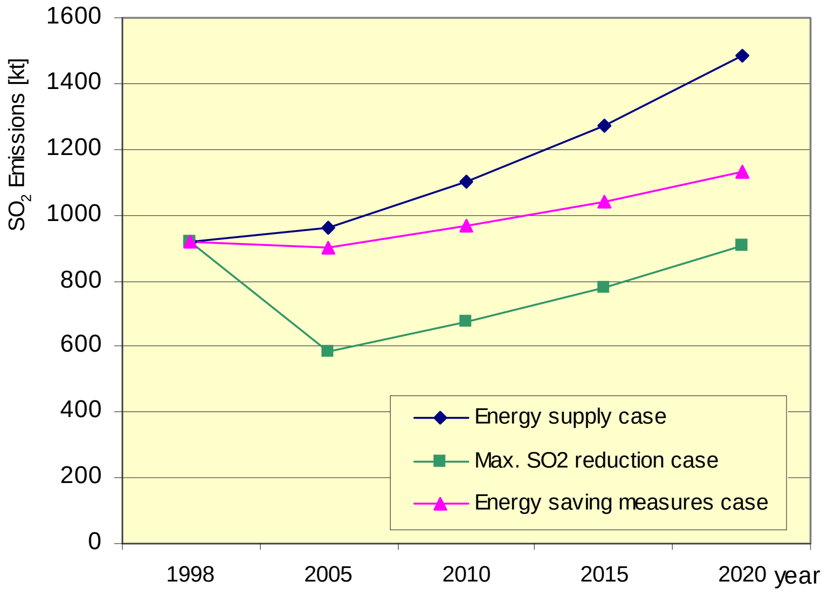
The model analysis shows that CO_2 emissions from the combustion of fossil fuels will reach 518 Mt in 2020. As Figure 4-26 demonstrates, CO_2 emissions would be reduced by nearly 26% at the end of study period. The largest source of CO_2 emissions comes from the transport sector with a share of 45% and followed by the residential/commercial sector with a share of about 29%. The industrial and electricity sector will be able to produce 18% and 15% of the total CO_2 emissions respectively. 17% reduction will ensue in the transport sector compared to the energy supply scenario. The industrial and electricity sectors with a share of 32% play an equal role in decreasing CO_2 emissions.

Figure 4-26: Reduction of CO_2 through Energy Saving Measures



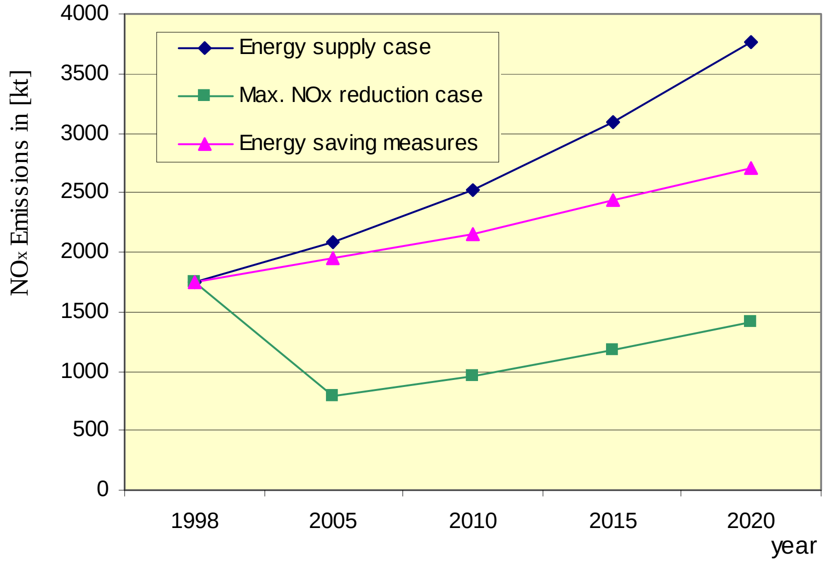
As a matter of fact, the implementation of energy saving policies reduces two other emissions based on the model results. Figure 4-27 shows the development of SO_2 emissions in the energy saving case compared with the energy supply scenario and environmental scenarios. After an initial drop in SO_2 emissions in the energy saving case during the 1998-2005 period, they will continue to increase slightly to 1,131 kt by 2020. This amount is 24% less than SO_2 emissions in the energy supply case and 17% more than the environmental scenario. A maximum reduction can be obtained through the oil sector, which has a reduction potential of 18%. The transport sector contributes 18% of SO_2 emission reduction to the energy supply case. SO_2 emissions in the electricity sector will not change significantly because more than 95% of power plants will consume gas from 2005 onwards.

Figure 4-27: Reduction of SO_2 Emissions through Energy Saving Measures



The development of NO_x emissions in the three cases (the energy saving, the energy supply and environmental scenarios) is shown in Figure 4-28. In the entire study period, NO_x emissions will increase at an average rate of 2% in the energy saving case, which is 1.5% less than the energy supply scenario. NO_x emissions will increase from 1.7 Mt in 1998 to 2.7 Mt at the end of the period. This amount is 29% lower than NO_x emissions in the energy supply case and 46% higher than the environmental scenario. The difference between the two scenarios compared to the SO_2 emission reduction case stems from the fuel type. Maximum reduction is achieved through the transport sector, which has a decrease potential of 18%. The residential/commercial sector contributes to 17% of the reduction of NO_x emissions. Contrary to SO_2 emissions, NO_x emissions from the electricity sector will decrease by 14% with the implementation of energy saving measures.

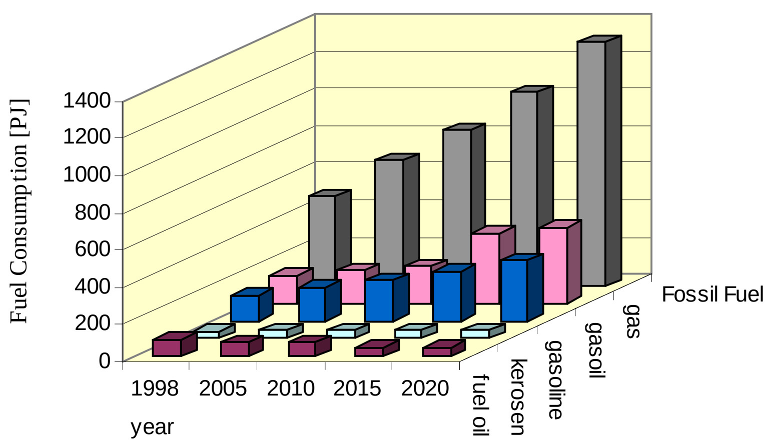
Figure 4-28: Reduction of NO_x Emissions through Energy Saving Measures



4.2 Emission Reduction Scenario for Tehran

This part attempts to develop a strategic plan for the emission reduction measures in Tehran. The emissions of SO_2, NO_x and CO_2 due to the energy consumption in the different sectors in Tehran have been analyzed. The study has also examined the reduction potential of energy consumption and emissions at a city level.

Figure 4-29: Fossil Fuel Consumption in Tehran



If the energy supply case without environmental restrictions is enforced and assuming that the final energy consumption of Tehran will rise according to the medium scenario, the consumption of fossil fuel in Tehran will grow during 1998-2020 as shown in Figure 4-29.

Considering the expansion of gas pipelines in Tehran and the substitution of oil by gas in the industrial and residential/commercial sectors, it is expected that gas consumption will rise with an average annual growth of 4.7% pushing its share up to more than 62% of the total energy consumption in Tehran by 2020. More than 73% of the total natural gas supplied in Tehran will be consumed in the residential/commercial sector and 18% by power plants and 9% by the industrial sector. As a matter of fact, the share of fuel oil and kerosene will decrease in the residential/commercial and industrial sectors. The share of gas oil in the total fossil fuel consumption will decrease from 19% in 1998 to 13% in 2020, while gasoline accounted for about 16% of the total fuel consumption in Tehran in 1998 its share will increase to 17% in 2020.

The rapid substitution of oil products by natural gas during the study period in the residential/commercial sector has changed the balance between the demand and supply in Tehran. In order to adjust the supply to this growth and the change in the consumption pattern, the structure of refinery production must be modified. Since, Tehran’s refinery was constructed before the expansion of gas, the structure of the refinery is designed to produce more kerosene, gas oil and fuel oil than gasoline to satisfy the demand in the residential/commercial and industrial sectors. As indicated by the model results, the other refineries will provide the additional demand of Tehran for oil products. Table 4-6 shows the capacity of Tehran’s refinery and the demand for oil products in 2020. The shortage of gasoline and gas oil will increase respectively to 245 PJ and 90 PJ due to the development of consumption in the transport sector. A surplus production of kerosene and fuel oil is expected in the future due to an increased gas consumption.

Table 4-6: The Production Capacity of Tehran’s Refinery and the Demand in Tehran (PJ)

	Fuel oil	Gas oil	Kerosene	Gasoline	LPG
Capacity	153	164	81	83	19
Tehran’s demand in 2020	73	254	42	329	18.6
Difference	+80	-90	+39	-246	+0.4

The changes in the consumption pattern of energy and its development in Tehran point toward a variation in the emission of pollution. Figure 4-30 displays the SO_2 emission sources and their respective share during the study period. The total SO_2 emissions are projected to increase from 137 kt in 1998 to about 168 kt by 2020. Assuming that all fuel oil will be substituted by gas in the electricity sector by 2005, SO_2 emissions will increase with an average annual growth of 0.9%. SO_2 emissions from power plants accounted for about 17% of the total SO_2 emissions in 1998.

According to the model results, the main source of SO_2 pollution will be the transport sector, contributing 46% of the total emissions in 2020. Since the capacity of Tehran's refinery will remain as before, it is expected that SO_2 emissions will not rise considerably. The contribution of industrial combustion sources to total SO_2 emissions is also projected to decrease from 22% in 1998 to 20% in 2020. This reduction is due to the rapid expansion of gas in the industrial sector. For the same reason, the share of the residential/commercial sector will decrease from 26% to 22% at the end of the surveyed period.

Figure 4-30: The Development of SO_2 Emissions in Tehran

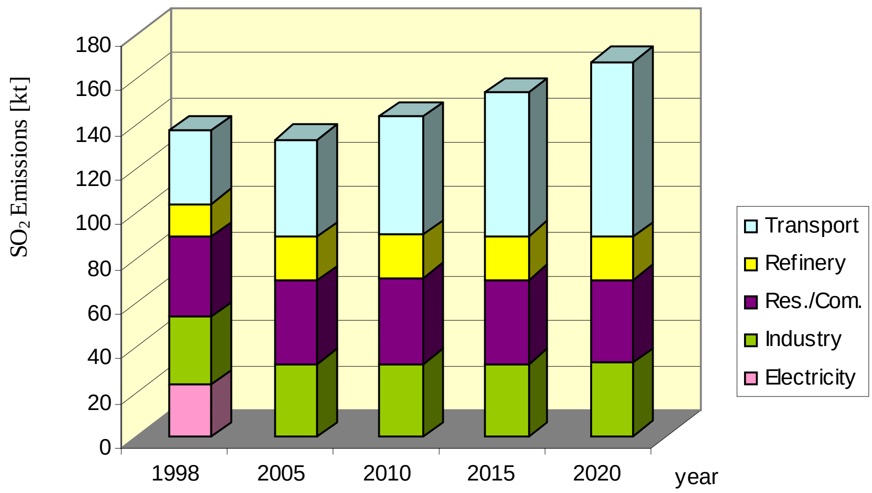
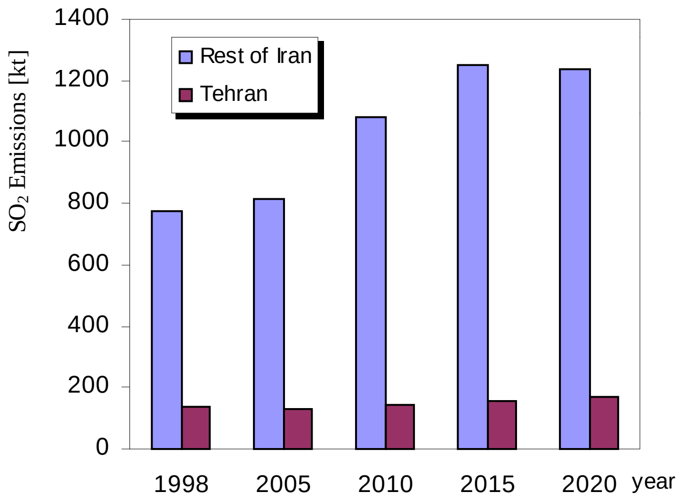


Figure 4-31 shows the expansion of SO_2 emissions in Tehran compared to the rest of the country. Tehran contributed 15% to the total emissions in 1998 and its share will fall to 11% by 2020. It is supposed that the gas pipelines in Tehran will be expanded earlier than in the other Iranian cities.

The impact of the energy supply strategy for Iran on the development of NO_x pollution in Tehran is shown in Figure 4-32. The total NO_x emissions are projected to rise from 235 kt in 1998 to about 561 kt by 2020. The major part of this increase arises from the transport sector, which contributes 70% and 81% to the total emissions in 1998 and 2020 respectively. The substitution of oil by gas in the electricity, industrial and residential/commercial sectors has caused a basic decrease in NO_x emissions. Gas substitution in all of Tehran's power generation facilities by 2005 will reduce the share of the electricity sector from 18% in 1998 to 6% in 2020.

Figure 4-31: The Development of SO_2 Emissions in Tehran Compared to the Rest of the Country



The contribution of the industrial and residential/commercial sectors to the total NO_x emissions is also projected to remain constant. The share of both the industrial and residential/commercial sectors will be 6%. This decrease of NO_x emissions is due mainly to the penetration of natural gas into the residential and industrial energy markets.

The development of NO_x emissions in Tehran compared to the rest of the country is displayed in Figure 4-33. Tehran contributed 19% to the total NO_x emissions in 1998. After an increase of its share to 27% in 2005, it will remain invariable up to the end of study period. Contrary to SO_2 emissions, the increase of fuel consumption in the transport sector is an important factor for stability in the share of NO_x emissions for the whole country.

Figure 4-32: The Development of NO_x Emissions in Tehran

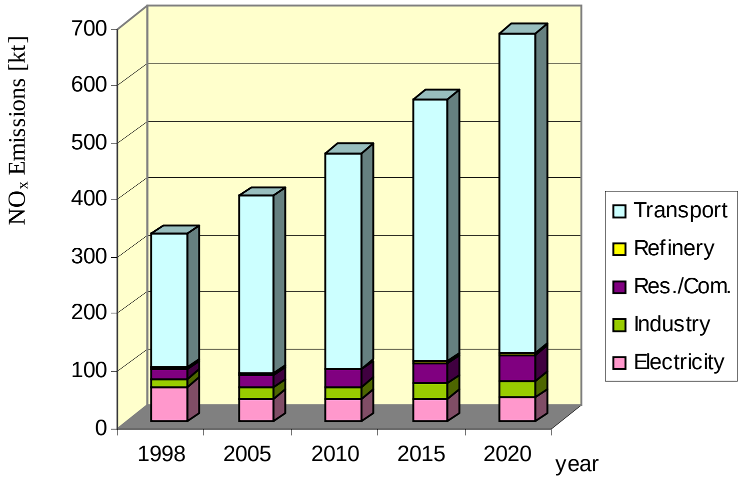
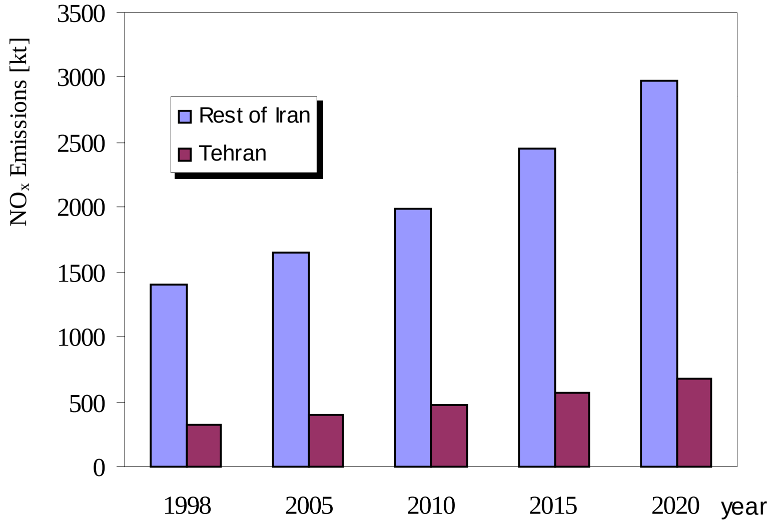


Figure 4-33: The Development of NO_x Emissions in Tehran Compared to the Rest of the Country

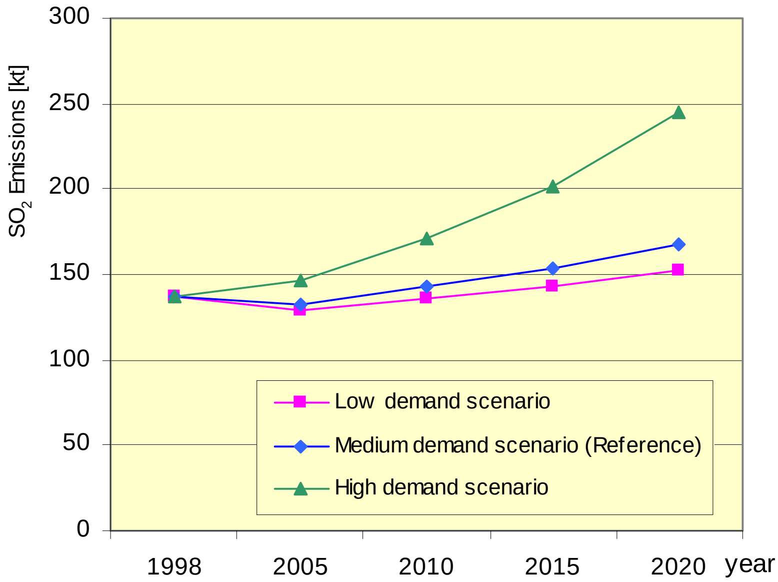


4.2.1 The Impact of Energy Demand Scenarios on the Growth of Emissions in Tehran

Figure 4-34 shows the result of variations in the demand forecast on the development of SO_2 emissions in Tehran during 1998-2020. In the low demand scenario, after a decrease in the amounts of SO_2 emissions from 137 kt in 1998 to 151 in 2005, they will grow to 569 kt at the end of the surveyed period. The initial reduction is due to the substitution of oil products by gas in Tehran's power plants. The model results show that SO_2 emissions will increase at an average annual rate of 0.45% in the low demand scenario. In the high demand scenario SO_2 emissions are projected to increase to nearly 243 kt in 2020, which is 45% higher than in the medium demand scenario.

Looking at the energy sectors in all demand scenarios, the amount of pollution in the residential/commercial and industrial sectors will remain constant due to the rapid change in the consumption pattern (gas substitution). In the model results, it is projected that the surplus of fuel oil produced in Tehran's refinery will be consumed by its utility, so that SO_2 emissions will not change significantly in this sector. The major contributor of SO_2 emissions will be the transport sector, where emissions will rise from 32 kt to 63 in the low demand scenario and to 152 kt in the high demand scenario during the study period.

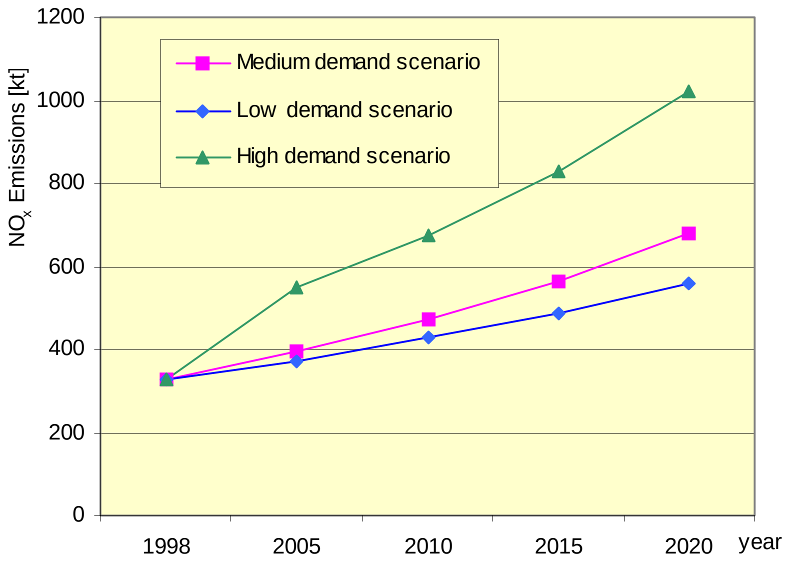
Figure 4-34: The Growth of SO_2 Emissions in Tehran for the Different Demand Scenarios



As Figure 4-34 shows, NO_x emissions in Tehran will develop more or less proportionally to its energy demand. For all demand scenarios, the NO_x emission projection indicates an increasing tendency during 1998-2020. In the medium demand scenario, NO_x emissions will increase from 338 kt in 1998 to 694 kt in 2020. In the low demand scenario, NO_x emissions will rise to 569 kt and their amounts are 18% lower than in the reference scenario. If the high demand scenario is applied, the development trend of NO_x emissions will be identical to the other scenarios but on a higher level. For the high demand scenario, emissions will increase to 1026 kt, nearly 48% higher than NO_x emissions in the medium scenario.

Like SO_2 emissions, the major source of NO_x emissions is the transport sector in all three scenarios. The share of this sector to the total NO_x emissions in Tehran will increase from 70% in 1998 to 80% in 2020 in the low demand scenario. This share will reach 85% in the high demand scenario. Considering that the model results recommended no additional capacity in the Tehran's power systems, NO_x emissions will remain constant for the electricity sector in both scenarios. The refinery in Tehran has the minimum share of total emissions. The industrial and residential/commercial sectors account for about 6% of the entire NO_x emissions in the low demand scenario. This share will rise to 7% for the industrial sector and will decrease to 4% for the residential/commercial sector. The most important reason of the above variation comes from the difference between the growth rate of the gas consumption in the two sectors.

Figure 4-35: The Growth of NO_x Emissions in Tehran for the Different Demand Scenarios



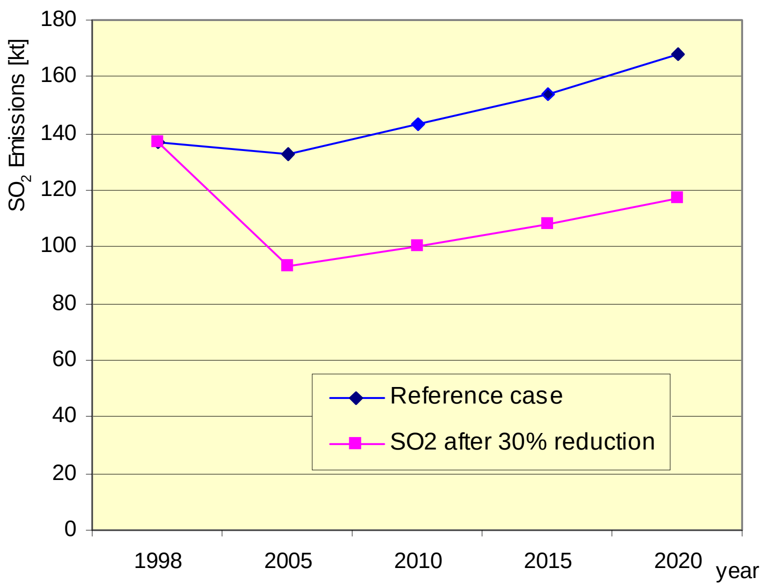
4.2.2 Emission Reduction Strategies in Tehran

- ***SO_2 Emission Reduction in Tehran***

As in the emission reduction strategies scenario for Iran, a constraint has been put on the maximum SO_2 emission level over the time period to reach a maximum achievable reduction. An annual reduction level of 10 to 30% has been executed to determine the maximum possible reduction of SO_2 emissions during the study period. Figure 4-36 shows the maximum reduction of SO_2 emissions at a level of 30%. Considering that oil cannot be substituted completely by gas in the final demand sector, a reduction of more than 30% annually is impracticable. The total SO_2 emissions range from 137 kt in 1998 to 114 kt at the end of surveyed period.

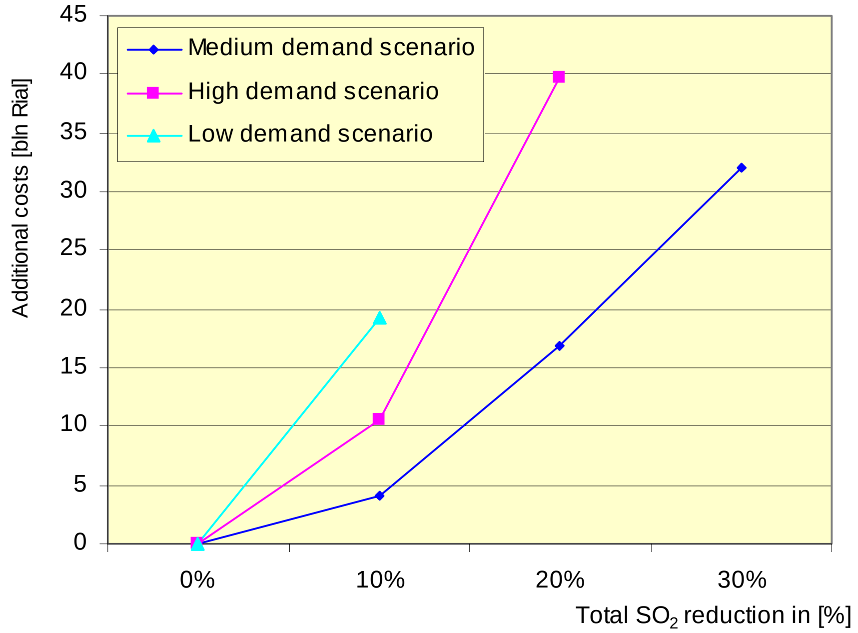
In the high final energy demand scenario, a maximum reduction is achieved at a level of 21%. This corresponds to SO_2 emissions of about 190 kt during 1998-2020, which is identical with the medium demand scenario. This is due to the fact that the consumption of sulphur content fuel is similar in both final demand scenarios. In the low demand scenario, the maximum achievable SO_2 reduction will be about 10% of the total emissions. They will remain constant in 2020 compared with SO_2 emissions in the base year.

Figure 4-36: SO_2 Emissions for a Maximum Reduction Level in Tehran



The variation in cost functions for the reduction of SO_2 emissions is shown in Figure 4-37. To reach an SO_2 reduction of 30% compared to 1998, about 32 billion Rials are required in the medium demand scenario. This amount is equal to about 10% of the total SO_2 emissions reduction costs for the energy and environmental strategy scenario. In the low demand scenario, the respective costs will be about 19 billion Rials, i.e. the total costs are 54% lower than in the medium demand scenario. For the high demand scenario, the total costs increase to 40.10^9 Rials.

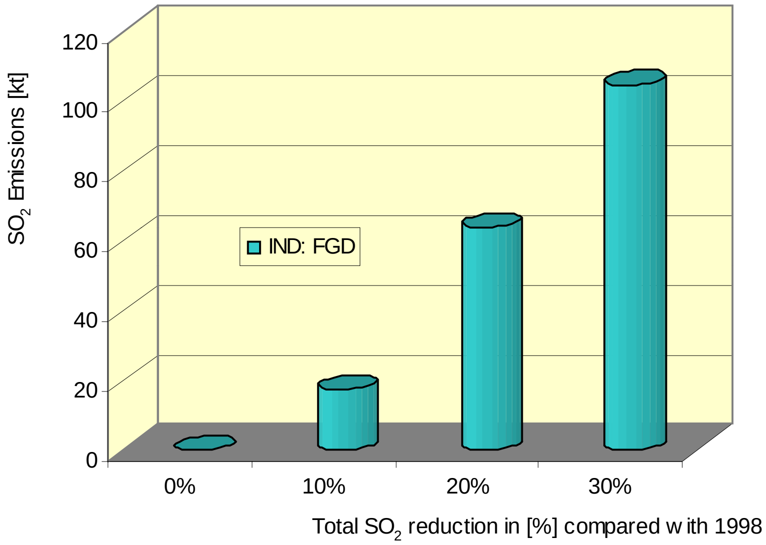
Figure 4-37: Marginal Cost of Total SO_2 Emission Reduction Compared with 1998 for



The emission control measures are ranked depending on the emission reduction level as displayed in Figure 4-38. For a level lower than 10% for SO_2 emission reductions by 2020, fuel oil will be substituted by gas oil in Tehran's refinery and the rest will be compensated for the installation of flue gas desulphurization facilities in the industrial sector. Since the complete substitution of oil by gas cannot practically be taken into account in the final demand, the continuation of SO_2 emissions reduction requires the installation of additional desulphurization facilities. It should be noted that in the results of the cost-efficient energy supply model, the fuel in all oil-fired power plants is changed to gas.

Considering the results of the model, the new investment will not be in the oil and electricity generation sectors of Tehran. Therefore, the industrial and residential/commercial sectors will remain the major sources of SO_2 emissions, which cannot be decreased by fuel substitution in the short term. If the SO_2 emissions are to be reduced by more than 30%, besides the substitution of gas oil by gas in Tehran's refinery, the installation of a wet limestone process is recommended for different operation levels in the industrial sector.

Figure 4-38: The SO_2 Abatement Measures



IND: FGD = Flue Gas Desulphurization for Industries

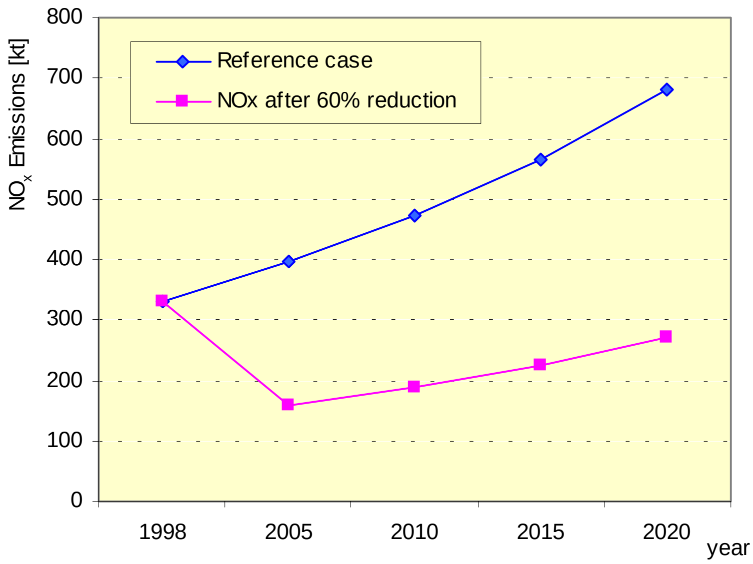
Additional foreign currency of about US$28 million is required to reach the maximum SO_2 emission reduction level in the medium demand scenario. This is about 10% of the total foreign costs for environmental strategies in the whole country. A 10% decrease in SO_2 emissions will require additional costs to the order of US$19 million in the low demand scenario. These costs amount to US$30 million for the reduction of 21% SO_2 emissions in the high demand scenario requires. Due to the rapid development of gas consumption in all energy sectors in Tehran and the reduction of fuel oil consumption, the difference between the volumes of foreign currency for the three scenarios is not high.

- ***NO_x Emission Reduction in Tehran***

A reduction level of 10 to 60% has been calculated for the emission reduction scenario for Tehran to analyze the NO_x emission reduction technologies. Figure 4-39 shows the maximum level of reduction of NO_x emissions. For a 60% level of reduction, NO_x emissions will remain lower than the reference case during the study period. The total emissions will range from 329 kt in 1998 to 204 kt, which is 15% lower than the emissions in the base year.

Similarly, the maximum achievable reduction will be 61% for the high demand scenario. In this case, the total NO_x emissions will decrease by about 2 Mt during the study period. This is 38% higher than the reference case in the same period. For the low energy demand scenario, the maximum achievable NO_x reduction will be about 60% of the total emissions. They will reach 1,067 kt during 1998-2020 and are 28% lower than in the base scenario.

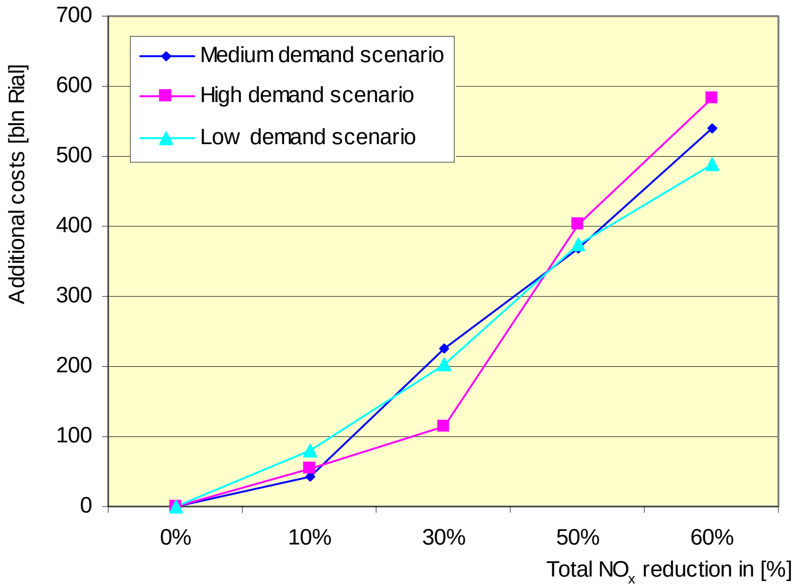
Figure 4-39: NO_x emissions for a maximum reduction level



The additional discounted costs for the different levels of NO_x reduction are shown in Figure 4-40. At a low reduction level of NO_x emission reduction in the three demand scenarios, the abatement costs will grow slightly due to the fuel switching in Tehran's refinery and the use of primary measures. To reach a minimum level of NO_x reduction in the medium demand scenario, these costs will increase to 540 billion Rials, which is 15% amounting to the same abatement costs as in the environmental strategy scenario for Iran. For a maximum NO_x reduction in the high demand scenario, the required costs are about 8% more than in the medium case. In the low demand scenario, the respective costs will be about 488 billion Rials, i.e. the total costs are 0.10% lower than in the medium demand basis scenario.

The function of different emission control measures in the total NO_x emission reduction compared to the energy supply case in 2020 is demonstrated in Figure 4-41. At a lower level of NO_x emission reduction, the fuel oil in all refineries is substituted by gas oil. At a level of 10% NO_x reduction, the installation of primary processes is recommended in the industrial and electricity sectors by considering the model results. At a level of 10% NO_x reduction the emission control measures for the transport sector (the installation of catalytic converters) have a low share.

Figure 4-40: Marginal Cost of Total NO_x Emission Reduction Compared with 1998 for Tehran

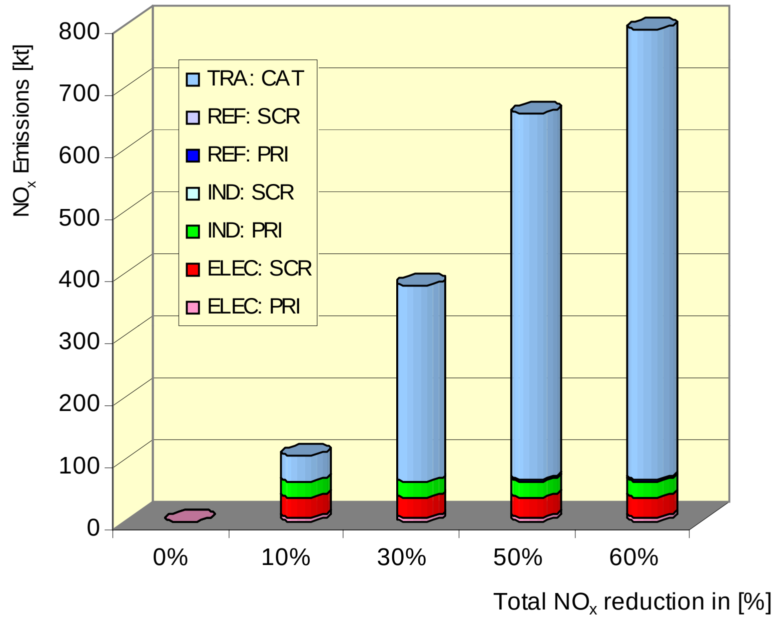


If the NO_x emissions are to be reduced further to a level of 60%, the set of NO_x emission reduction measures is almost the same, even on the different operating levels of emission reduction for vehicles. Since the most important source of NO_x emissions is the transport sector in Tehran, the installation of catalytic converters in vehicles will contribute greatly to overall reduction. At all levels of reduction, the use of catalytic converters has the greatest share of in the decrease of NO_x emission. At a maximum reduction level, it will contribute with a share of 91% for NO_x emission reduction, even if all fuel combustion in cars were controlled with the use of catalytic converters.

The additional foreign currency required for a maximum reduction of NO_x emissions in the medium scenario is estimated to be US$692 million. The model results reveal that Tehran requires 17% of the total foreign currency for the reduction of NO_x emissions compared to the whole country. Based on the total emission reduction costs, with a share of 99% the transport sector has the largest share of foreign currency costs. For a 60% reduction of NO_x emissions

US$560 million are required in the low demand scenario, which is 20% lower than the costs in the medium demand case. In the high demand scenario, US$1,035 million are required for an emissions reduction of 61%.

Figure 4-41: Ranking of the NO_x Abatement Measures in Tehran



ELEC = Electricity Sector
IND = Industry Sector
REF = Refinary
TRA = Transport

PRI = Flue Gas Desulphurization
SCR = Selective Catalytic Reduction
CAT = Primary NO_x Reduction Technology

- ***NO_x and SO_2 Emissions Reduction in Tehran***

By applying restrictions on the total emissions of both pollutants, cost-efficient strategies can be developed for every combination of SO_2 and NO_x target emission values. The effects of such combined reduction strategies on the energy system costs of Tehran are shown in Figure 4-42. It is expected that the control cost of a combined reduction of SO_2 and NO_x will be lower than the sum of the costs of the separate reduction of the pollutants. Similar to the results for the whole country, the simultaneous reduction of SO_2 and NO_x emissions in Tehran will not change the costs significantly. This is due to the fact that the potential for fuel switching in the environmental case is very low and it can be applied only to Tehran's refinery.

Figure 4-42: Marginal Abatement Costs for Combined NO_x and SO_2 Reduction

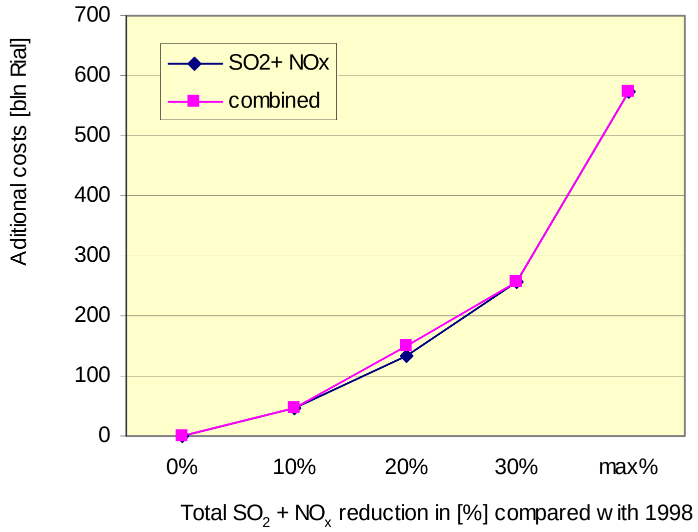
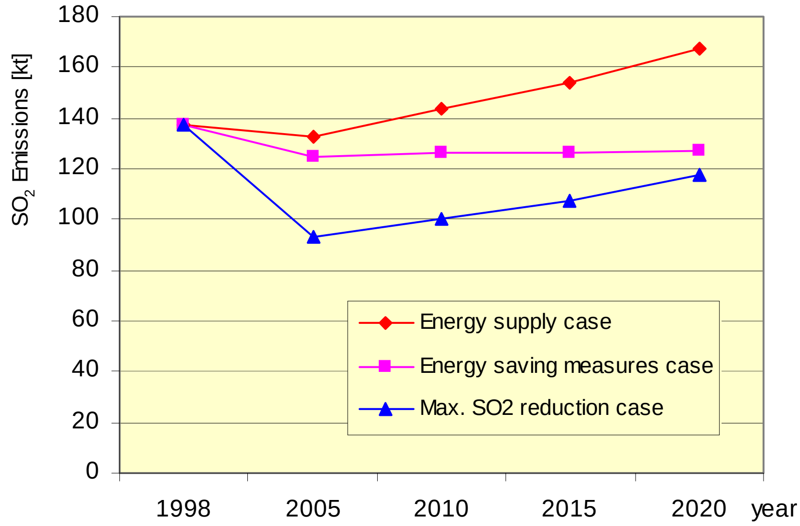
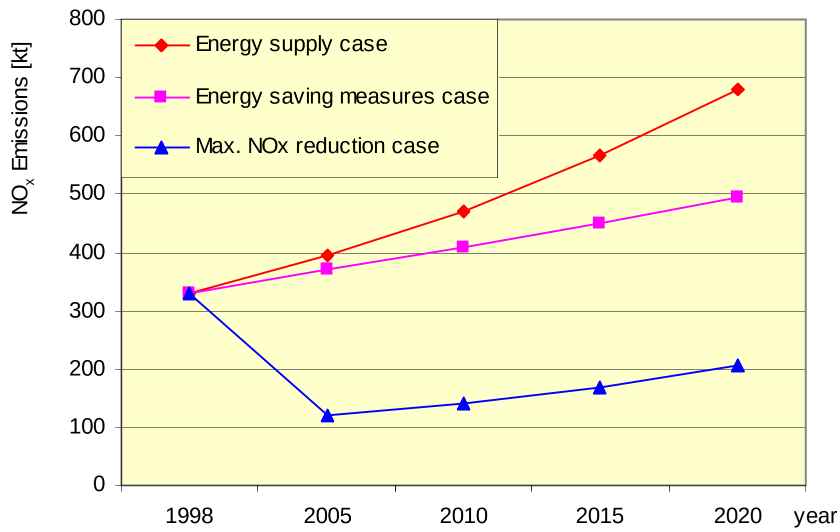


Figure 4-43: Reduction of SO_2 through Energy Saving Measures in Tehran



The effects of energy saving policies have also been analyzed for the emission reduction in the capital city. Figure 4-43 shows the development of SO_2 emissions in the energy saving case compared with the energy supply scenario and environmental scenario for Tehran. After an initial drop in SO_2 emissions in the energy saving case during 1998-2005, SO_2 emissions will remain constant for the rest of the study period. The emissions reach 127 kt, which is 25% less than the SO_2 emissions in the energy supply case and 8% more than in the environmental scenario. The maximum reduction will be obtained through the transport sector, which has a reduction potential of about 53%. The residential/commercial and industrial sectors contribute 30% and 17% of SO_2 emission reductions respectively compared to the reference case. The emissions in the electricity and oil sectors will not change as a result of gas substitution.

Figure 4-44: Reduction of NO_x through Energy Saving Measures in Tehran



The development of NO_x emissions in the above mentioned cases, is also shown in Figure 4-44. In the energy saving case, NO_x emissions will increase to 2,055 kt during 1998-2020 in Tehran, which is 16% lower than in the energy supply case. This amount is three times more than the NO_x emissions in the environmental scenario. The difference between the two scenarios and the SO_2 emission reduction case comes from the gas potential for NO_x reduction. Like SO_2 emissions, the maximum reduction will be obtained through the transport sector, which has a decrease potential of about 90%. The residential/commercial and industrial sectors contribute 7% and 3% of NO_x emission reductions respectively to the energy supply case. The electricity and oil sectors play an insignificant role in emission reduction in the energy saving case. They have a small potential for the conservation and substitution of oil by gas.

4.3 Externalities Impacts Scenario for Tehran

The effects of externalities on the results of the strategic plan for the emission reduction measures in Tehran have been analyzed in the externalities impacts scenario for Tehran. According to the results of the energy supply case for Tehran, it is expected that the share of NO_x emissions in the total emissions in Tehran will increase from 19% in 1998 to 27% in 2020. SO_2 emissions contributed 15% to the total emissions in 1998, and their share will fall by 11% in 2020. Naturally, the high concentration of pollution in Tehran involves a great amount of externalities. The actual changes in the emission reduction costs have been analyzed and the role of different sectors in the increase of externalities has been estimated.

The emissions of SO_2 and NO_x due to the change in the externalities in Tehran have been studied. The model has also estimated the increase of externalities for the different energy demand scenarios on a city level. The energy model with environmental restrictions has been enforced and the real costs for emission reduction measures have been calculated considering the externalities. The effects of conservation potential in the different energy sectors on the reduction of externalities have been taken into account.

Figure 4-45: Externalities Arise from Energy Consumption for the Different Sectors in Tehran

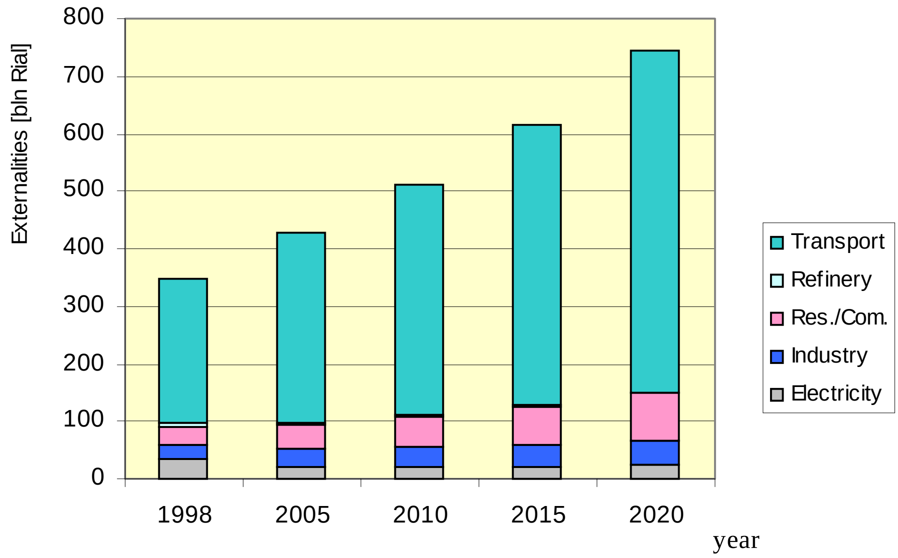
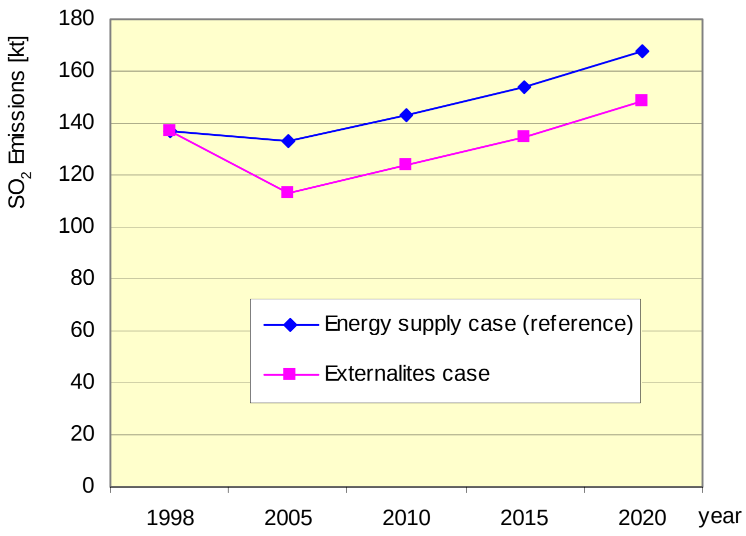


Figure 4-45 illustrates the impact of the energy supply case for Tehran on the development of externalities. Total externalities are projected to increase from 348 billions Rial in 1998 to 744 billions Rial in 2020 i.e. with an average annual growth of 6.6%. As the transport sector is a major source of SO_2 and NO_x pollution in Tehran, it is obvious that most growth in the externalities will be in this sector. The transport sector will contribute 33% and 80% to the total externalities in 1998 and 2020 respectively.

The contribution of the residential/commercial sector is projected to rise from 9.6% in 1998 to 10.8% in 2020. The small share of this sector and industries to the development of the total externalities comes from the increasing substitution of fuel oil by gas. The externalities of thermal power plants in Tehran will decrease by 35% compared to the base year, due to the complete substitution of oil by gas from 2005 onwards.

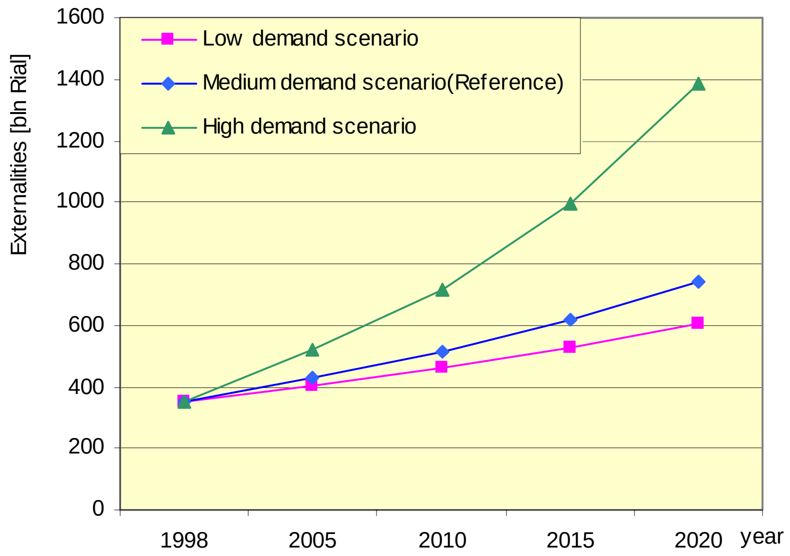
By including the externalities in the energy supply model for Tehran, it is expected that the mix of fuel consumption in the energy production and conversion system will move toward cleaner fuel. The model results recommend the usage of gas instead of gas oil in Tehran's refinery from 2005. This substitution will cause a steady reduction in SO_2 emissions during 2005-2020 as shown in Figure 4-46. The total SO_2 emissions will decrease from 734 kt to 645 kt i.e. a 10% reduction compared to the energy supply case. Contrary to SO_2 emissions, the significant difference in the development of NO_x emissions will not be obtained due to the similarity emission factors in gas and gas oil.

Figure 4-46: The Development of SO_2 Emissions Considering Externalities



The effects of variation in the demand forecast on the development of the total externalities are shown in Figure 4-47. The results show that the total externalities increase with an average annual rate of 3.5% in the medium scenario which is comparable to the energy consumption rate. The sum of externalities will reach 2,649 billions Rials at the end of study period. In the low demand scenario, the total externalities are expected to increase to nearly 607 billions Rials by 2020 i.e. with an average annual rate of 2.6%. This is 18% lower than in the medium scenario. Looking at the development of externalities in the high scenario, the structural changes are stronger than in the case of the medium growth rates. The model results show that externalities will increase from 348 billions Rial in 1998 to 1388 billions Rial in 2020. This amount is about twice the costs in the medium demand case.

Figure 4-47: Total Externalities for the Different Demand Scenarios



If environmental restrictions are enforced and assuming that the final energy consumption will increase according to the medium scenario and the maximum emission reduction is as defined in the reference case for the Tehran scenario, the total costs of emission control measures will develop as in Figure 4-48. The upper part of the chart indicates the costs of emission reduction measures without considering externalities. These costs will increase together with the rising total emissions. It is estimated that the total reduction costs will be 1,224 billion Rials during the study period. If externalities are added to the total reduction costs, it is expected that a significant decrease in the reduction costs will occur. The effects of externalities on the total costs of emission control measures are shown in bottom part of chart. Indeed, if the reduction measures are applied, the costs would not only increase in the energy system but would also benefit from the reduction of externalities. The benefit from externalities will be 90 billion Rials during 1998-2020.

Figure 4-48: Total Costs of Emission Reduction for Tehran Considering Externalities

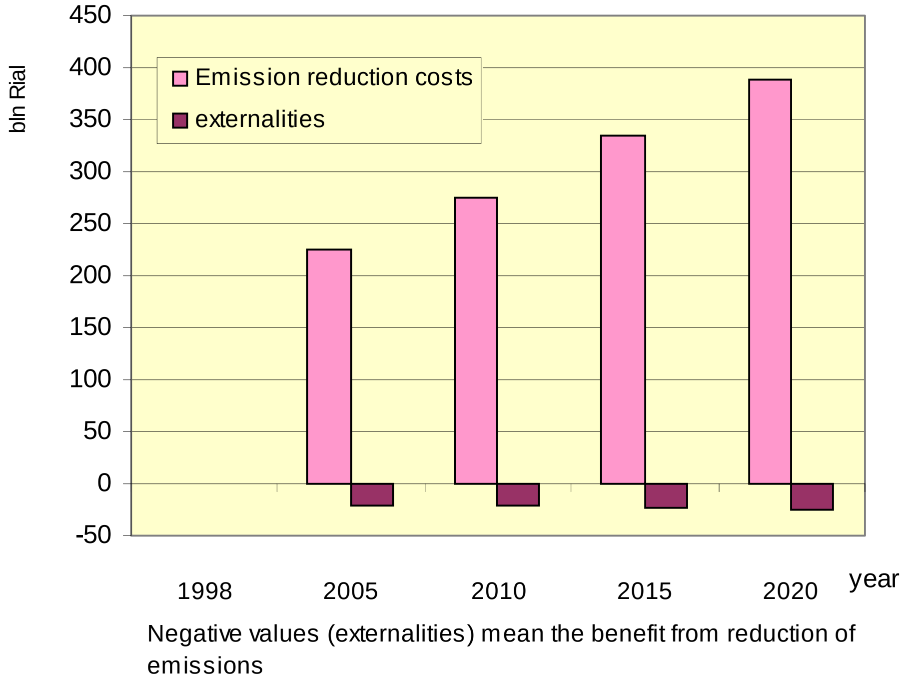
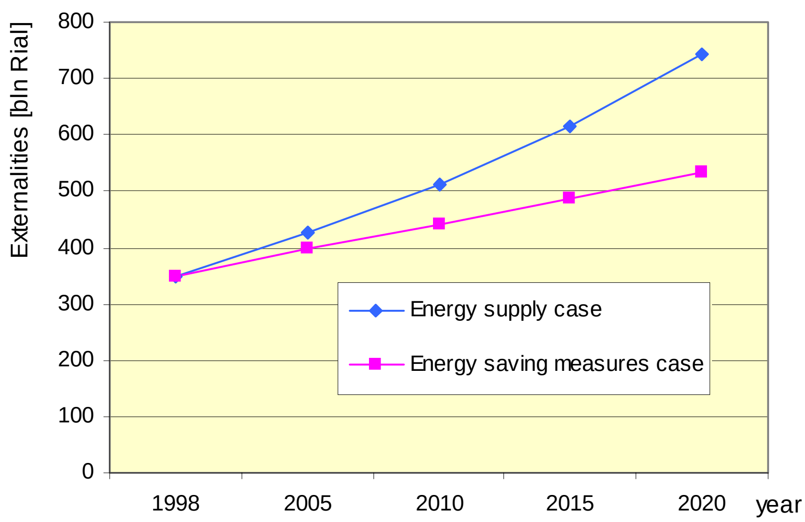


Figure 4-49: The Reduction of the Total Externalities through Energy Saving Measures



If the energy saving measures are put into effect, the total externalities will drop to 2207 billions Rials, i.e. a 17% reduction during the study period compared to the reference scenario. As a matter of fact, the implementation of energy saving policies will reduce SO_2

and NO_x emissions. Consequently, it is expected that a reduction of the externalities will ensue. Figure 4-49 shows the development of externalities in the energy saving case compared with the energy supply scenario.

Summary and Conclusions

The energy situation in Iran is becoming more and more complex. The oil revenue plays a significant role in the development of the Iranian economy. The growing dependence of the economy on the oil revenue as a major source of foreign exchange means that economic growth is associated with the growth and fluctuations in the oil export revenue. Energy consumption increases as a consequence of economic development, population growth and the improvement of living standards. As a result, the domestic demand swallows the export capacity of oil produced in Iran. Therefore, the management of energy resources is an important issue in Iran and has a significant impact on the economic development.

Iran is faced with environmental problems due to the growth of energy consumption, low quality fuels, inefficient methods of energy production and use, the poor conditions of vehicles and the lack of emission control measures. The major environmental problem is air pollution in the capital city of Iran (Tehran). A rising urban population, lack of planning controls, increased concentration of industry in and around Tehran and automobile traffic have resulted in severe air pollution. The absence of emission control measures is threatening human health and undermining the productivity of Tehran's population. To ensure that the management of energy resources takes place with minimum damage to the environment, it is necessary to integrate environmental considerations into energy planning and policy making.

An adequate energy environmental planning tool should reflect the country specific problems in the energy fields such as: consideration of regional imbalances, foreign exchange requirements and management of exhaustible resources. A flexible tool for planning the energy and environmental system must be able to analyze the effects of foreign exchange shortages on the structure of the energy system and to consider regional imbalances of the country. The EFOM-ENV model will be capable of considering these requirements after certain modifications.

This study has developed cost-efficient energy supply strategies for the reduction of SO_2, NO_x and analyzed the impact of these reductions on the growth of CO_2 emissions in Iran. To reach this objective, the multi-period linear programming model EFOM-ENV was used. Based upon a detailed analysis of the energy supply system in Iran and its environmental influences, the model has been modified to adequately represent the energy system of Iran. This modification includes the representation of energy conversion and the emission control measures and technologies in the model, as well as technological and economic data on the existing technologies and possible future ones. Furthermore, additional changes have been added to the model to comply to regional emission restrictions for Tehran and the impact of externalities on energy and environmental strategies for Tehran has also been analyzed with the changes of costs functions.

The results of the model application for the three following scenarios have been analyzed:

- Energy supply and emission reduction strategies for Iran
- Emission reduction scenario for Tehran
- Externalities impacts scenario for Tehran

For each scenario, a cost-efficient energy supply has been defined as a reference scenario. The energy supply model has been solved and analyzed with emission control restrictions. This reference scenario serves as a basis for the analysis of different energy supply and emission control strategies and the effects of variations in important input parameters. The model results for energy supply and emission control strategies have been used for the analysis and evaluation of the results of the model results for the emission reduction scenario for Tehran. The impact of externalities arising from the energy consumption in Tehran on emission control strategies has been analyzed.

The main emphasis has been laid on the elaboration of reduction strategies for SO_2 and NO_x emissions due to the health effects in the large cities and acid rain. Since no reliable data on the level of the total emissions is available and no emission reduction measures have yet been enforced in Iran, the model has estimated the growth of SO_2 and NO_x emissions and developed adequate emission control strategies. The reduction of CO_2 emissions has also been considered with the development of energy conservation measures and the expansion of gas consumption.

The major aims of this study can be briefly summarized as follows:

- An energy-environmental planning tool has been developed on the basis of the analysis of the actual structure of the energy supply system and of future technological options for energy supply and emission reduction for Iran.
- Emission control strategies have been developed for the reduction of SO_2, NO_x and SO_2 emissions in Iran.
- An energy-environmental planning tool has been modified to obtain emission control strategies, focusing on emission reduction in the capital city (Tehran).
- The impact of externalities on emission reduction strategies for Tehran has been analyzed with related to the changes in the objective function of the model.

The robustness of the results obtained for the reference energy scenario has been assessed by varying assumptions. Since the model results are influenced by the projected final energy demand, three demand scenarios have been defined with regard to the future economic development of Iran with emphasis on a fast growth of population. Due to the importance of the population growth in the final energy consumption, it is expected that the energy consumption in the residential/commercial sector will continue to increase at higher rates than the other final sectors. On the basis of official reports on energy demand forecasts, low, medium and high scenarios have been defined. The reference scenario in this study is based upon the medium scenario with an average annual rate of about 4.3%.

By applying the reference energy strategy without enforcing emission restrictions, it is expected that a slight decrease in the consumption rates of oil and its related products will ensue. To an increasing extent, natural gas will contribute to the country's mix of primary energy carriers and its share will remain highest until 2020. The above trend in the energy consumption will be more or less seen in the low and high final energy demand scenarios. To expand the electricity supply, highest priority has been given to the development of the combined cycle power plants. Due to some hydroelectric, thermal, and nuclear power plants already under construction, the new investment has been considered in 2020.

The increase in energy consumption has significant effects on the export of oil and consequently its revenue. The model results reveal that oil exports will be reduced to 44% compared to the reference case. It is expected that the oil revenue will rise until 2005 and then will fall by 0.8% compared to this year.

Considering the three official exchange rates in Iran, if the exchange rate of US$ is supposed to be the highest rate (US$ = 8000 Rials), the model will select those technologies or energy carriers which involve less foreign currency. In this case, the combined cycle power plants are substituted by gas turbines.

According to the model results obtained for the energy supply strategies scenario, SO_2 emissions will continue to increase in the future. Due to the increasing consumption of natural gas in the industrial and residential/commercial sectors and complete substitution of oil by gas, SO_2 emissions will continue to rise after a temporary drop. This increase mainly involves the transport sector, which has contributed more than 37% to the total SO_2 emissions but also the industrial and the residential/commercial sectors.

NO_x emissions will increase at a higher level than SO_2 emissions in Iran. Most of this increase arises from the transport sector, which will contribute 76% of the total emissions in 2020. The substitution of oil by gas in the power plants will decrease the share of NO_x emissions to 5% in 2005 and afterwards it will remain more or less stable until 2020. In the low demand scenario, NO_x emissions are 30% lower than in the medium demand scenario. In the high demand scenario, they are nearly 70% higher.

The increase of CO_2 emissions is proportional to the development of the final energy demand i.e. they will rise with an annual growth rate of 4%. For all three scenarios, the model results show the same trend for CO_2 emissions.

Considering the increase of emissions, the need for emission control strategies in Iran is obvious. By the development of cost-efficient emission control strategies, a 39% reduction of SO_2 emissions and 61% reduction of NO_x emissions during 1998-2020, compared to the projected level of the energy supply case, can be attained. By varying the required target level of total emissions, emission control cost functions can be determined for the reduction of SO_2 and NO_x individually and for the simultaneous reduction of both pollutants. The cost-curves calculated for SO_2 and NO_x reduction reveal a robust model behavior for the applied scenarios.

By analyzing the results, the following measures can be recommended for a cost-efficient emission reduction compared to the energy supply case:

The most cost-efficient measures for reducing SO_2 emissions are fuel switching from fuel oil to gas, technology conversion in the new power plants, and the installation of flue gas desulphurization units in the power plants and the industrial heating boilers. For technology substitution the construction of gas-fired combined cycle power plants in the energy supply case and emission restriction scenario is recommended. The major part of the SO_2 reduction is due to the installation of flue gas desulphurization units in the industrial heating boilers, which have no access to the natural gas. If higher SO_2 reduction rates are to be achieved, flue gas desulphurization units in the industrial sector will appear on a higher level.

The most cost-efficient measures to reduce NO_x emissions are the primary measures in the power plants. For higher NO_x reduction rates, the application of control measures in the transport sector are suggested. Major effects on the overall NO_x emission reduction are achieved through the installation of catalytic converters for cars, which are more strongly affected by the projected transportation activity.

Furthermore due to the low potential of fuel substitution in the emission reduction scenario, the results of the model show no significant difference between the simultaneous and individual reduction of SO_2 and NO_x emissions. Compared to a separate reduction of SO_2 and NO_x emissions, emission control cost savings in the range of 2% can be achieved by a combined strategy in Iran.

Since no specific CO_2 removal technologies have been introduced into the model, the possibilities for reducing CO_2 emissions are mainly through fuel substitution and technology switching options. Energy efficiency improvements cut CO_2 emissions in an economic way. It is supposed that the total energy saving potentials are 6%, 20%, and 30% respectively for the conversion, industrial, and residential/commercial sectors. If energy saving measures were put into effect, CO_2 would be reduced by nearly 26% at the end of the study period. The maximum reduction will ensue in the transport sector with a share of 17% compared to the reference scenario.

As a matter of fact, the implementation of energy saving policies reduces also the two other emissions. After an initial drop in SO_2 emissions in the energy saving case, it will continue to increase slightly by 2020. SO_2 and NO_x emissions will be 24% and 29% lower respectively than in the reference case and 17% and 46% higher than in the environmental scenario.

The model has also been modified for the development of strategic plans for emission reduction measures in Tehran. The emissions of SO_2, NO_x and CO_2 due to the energy consumption in the different sectors in Tehran have been analyzed. The study has also examined the reduction potential of energy use and emissions on a city level.

Considering the expansion of gas pipelines in Tehran and the substitution of oil by gas in the industrial and residential/commercial sectors, it is expected that the share of gas consumption will rise by more than 62% of the total energy consumption. In fact, the share of fuel oil and kerosene will decrease in the residential/commercial and industrial sectors. A rapid substitution of oil fuel by natural gas during the study period in the residential/commercial sector has changed the balance between the demand and supply in Tehran. In order to adjust the supply to this growth and change in the consumption pattern, a modification in the structure of refinery production is recommended.

The changes in the consumption pattern of energy and its development in Tehran point toward the variations in emissions of pollution. Assuming that all fuel oil will be substituted by gas in the electricity sector from 2005, SO_2 emissions will increase with an average annual growth of 0.9%. The main source of SO_2 pollution will be the transport sector, contributing 46% of the total emissions at the end of study period. The contribution of industrial combustion sources and the residential/commercial sector to the total SO_2 emissions is also projected to decrease due to the rapid expansion of gas.

Tehran contributed 19% of the total NO_x emissions in 1998. After an increase to 27% in 2005, it will remain unchanged until the end of the study period. The largest portion of NO_x emissions originates from the transport sector. The contribution of the industrial and residential/commercial sectors to the total NO_x emissions is also projected to remain constant. The main reason is due to the penetration of natural gas into the residential/commercial and industrial sectors.

The result of variations in the demand forecast on the development of SO_2 and NO_x emissions in Tehran has been analyzed. Looking at the energy sectors in all demand scenarios, the amount of SO_2 emissions in the residential/commercial and industrial sectors will remain constant due to the rapid change in the consumption pattern (gas substitution).

As shown in the emission reduction strategies scenario for Iran, a constraint is put on the maximum SO_2 emission level over the time period to reach a maximum achievable reduction. Considering that oil cannot be substituted completely by gas in the final demand sector, a reduction of more than 32% is impracticable. The maximum achievable emission reduction is calculated for the two other energy demand scenarios. Similarly, the maximum achievable reduction will be 63% for NO_x emissions.

The emission control measures are ranked depending on the emission reduction level for SO_2 and NO_x emissions. For the lower level of SO_2 emission reduction, fuel substitution is recommended for Tehran's refinery and flue gas desulphurization facilities for the industrial sector. Considering the model results, any new investment will be put into the oil and electricity sectors of Tehran. Therefore, the industrial and residential/commercial sectors will remain the major sources of SO_2 emissions, which cannot decrease emissions by fuel substitution in the short term period. If SO_2 emissions have to be reduced on a higher level, flue gas desulphurization should be installed at different operational levels for the industrial sector.

Like SO_2 emissions, in the lower level of NO_x emission reduction, the fuel oil in all refineries is substituted by gas oil and the installation of primary processes is recommended in the industrial and electricity sectors. Emission control measures for the transport sector are applied for a low level of NO_x emissions reduction. If NO_x emissions are to be reduced further, the set of NO_x emission reduction measures is almost the same even for the different operational levels in the emission reduction for vehicles.

By applying restrictions on the total emissions of both pollutants, cost-efficient strategies can be developed for every combination of SO_2 and NO_x target emission value. The effects of such combined reduction strategies on the energy system costs of Tehran is the same as the results for Iran. Simultaneously the reduction of SO_2 and NO_x emissions in Tehran does not change the costs significantly. This is due to the low potential of fuel switching in the emission reduction case. Fuel substitution can only be applied for Tehran's refinery by the model.

The effects of energy saving policies have also been analyzed for emission reduction in the capital city. By applying the energy saving measures in the model, SO_2 emissions will develop 25% less than in the energy supply case and 8% more than in the emission reduction scenario. The maximum reduction can be obtained through the transport sector, which has a decrease potential of about 53%. For the NO_x case, emissions are three times more than NO_x emissions in the emission reduction scenario and 16% lower than in the energy supply scenario. A maximum reduction is achievable through the transport sector, which has a reduction potential of about 90%.

The model has also been modified to consider the effects of externalities on the development of a strategic plan for emission reduction measures in Tehran. The high concentration of pollution in Tehran involves a great amount of externalities. The actual changes in the reduction costs have been analyzed and the role of different sectors in the increase of externalities has been estimated. The emissions of SO_2 and NO_x due to the change in externalities in Tehran have been studied. The model has also examined the increase of externalities for the different energy demand scenarios on a city level. The energy supply model with environmental restrictions is enforced and the real costs of the emission reduction measures have been calculated considering the externalities. The impact of the conservation potential on the reduction of externalities in the different energy sectors has been taken into account.

As the transport sector is a major source of SO_2 and NO_x emissions in Tehran, it is quite obvious that most growth in the externalities originates from this sector. The transport sector will contribute 80% to the total externalities in 2020. The residential/commercial and industrial sectors have a small share in the total externalities due to the increasing replacement of oil fuel by gas. By applying the externalities in the energy supply model for Tehran, the usage of gas instead of gas oil is recommended in Tehran's refinery from 2005. This substitution will cause a steady reduction in SO_2 emissions between 2005-2020.

If externalities are added to the total reduction costs in the emission reduction scenario, a significant decrease in emissions compared to the model without externalities is expected. Indeed, if the reduction measures are applied, not only an increase of costs is expected but also there would be a benefit from the reduction in externalities. The implementation of energy saving policies reduces two emissions according to the model results and consequently a reduction in externalities will ensue.

One of the difficulties in conducting this study dealing with a development model for Iran is the provision of a reliable database in the energy sector. Since the accuracy and the assumptions underlying the determination of the data may be a critical factor in such large-scale system analytical applications, the annual energy reports on energy production and consumption and emission pollution which are available from The Ministry of Energy have been used. The operating and cost data used in this study were taking from different reports of the Ministry of Oil and the Ministry of Energy. In cases, where official data was not available, they have been estimated by using internationally accessible information and the database in the IIP.

The energy environmental model for Iran can be applied for various energy related-studies and the assessment of air pollution control strategies. Although most data describing the energy supply system has been obtained from the Iranian institute, there has been no comprehensive information basis covering the whole energy supply system available in Iran up to now. Therefore, the database had to be completed in most of part with regard to emission data at a technological level, economic and technological data on emission control technologies and future energy conversion technologies.

An expansion of the model can be made with more detailed information on the energy conversion processes in the final sectors. This is necessary to represent the end-use oriented emission control measures, such as process substitution, energy conservation or the application of emission control technologies. However, for this kind of extension, reliable data must be available.

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