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Energy consumption and CO_2 emissions in Turkey: Empirical analysis and future projection based on an economic growth

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Abstract

In this study, Turkey's energy sector was overviewed during the period of 1970–2002. The total energy consumption (TEC) was modeled by using the economic growth (proxied by gross national product—GNP) and population increase, which are the two important factors to determine the energy consumption for developing countries. In addition, the relationship between the TEC and total CO_2 (TCO_2) emission was studied. For this purpose, regression analysis was performed and the strong relationship between TEC and TCO_2 ($R^2 = 0.998$) was modeled. Also, results showed that a regression model can be used to predict the TEC from the country population and the GNP with high confidence ($R^2 = 0.996$).

Using the models developed in the study, TEC as a function of the targeted economic growth (annual rate of GNP increase) published in the National Development Plan and TCO_2 based on the TEC were forecasted up to year 2015. Additionally, the TCO_2 was also calculated by the intergovernmental panel on climate change (IPCC) method and the results from the two methods were compared. It was seen that the values predicted by IPCC method were considerably higher.

Based on the findings of the study, some recommendations were presented to be considered for the future energy policies to conform to the Framework Convention on Climate Change signed by Turkey on 18 December 2003.

Keywords: Turkey; Regression; CO_2

1. Introduction

Development plans, which are the guiding principles for private investments and the mandatory rules for state institutions, have been prepared every 5 years since 1963 in Turkey. After the beginning of the development plans, the political decisions regarding all sectors have been made according to these plans. Targeted economic growth based on the rate of the population increase is one of the bases for the constitution of the policies about the sectors in the development plans.

In the beginning, these plans were designed to encourage the short-term economic benefits disregarding the environmental problems in Turkey, like in many developing countries. Therefore, these plans have not included any information regarding the environmental problems that will be caused by the economic growth and the recommendations to reduce the impact of these problems.

Economic growth rate of all the sectors in Turkey has been raised by several factors, particularly the free market economics introduced in the 1980s. The growth of the sectors, especially in the industry, resulted in considerable increase in energy consumption. Since 1970, the energy consumption increased by 415% and reached 79 million ton of oil equivalent (mtoe) (Energy Statistics, 2003) while CO_2 emission increased by 410% and reached 200 million ton (SIS, 2003).

Large-scale energy production plants established to meet the demand resulted from the increased population and growing economy have negative domestic and cross-border effects on the ecological balance. The main source of the CO_2 emission due to the fuel consumption (FC) is the thermic power plants which uses fossil fuels in Turkey. The second important source is the industry. CO_2 emission

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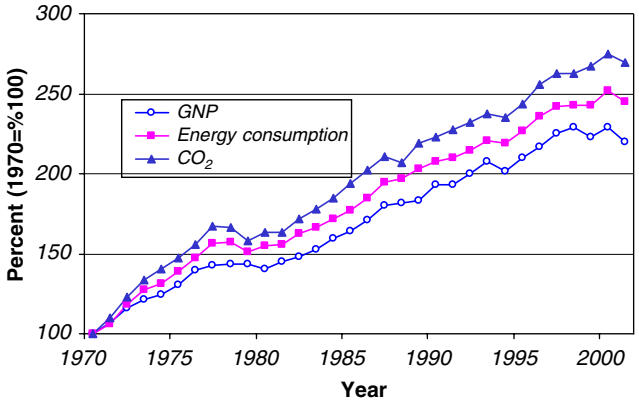

Fig. 1. Relationship between GNP, energy consumption, and CO_2 emission in Turkey.

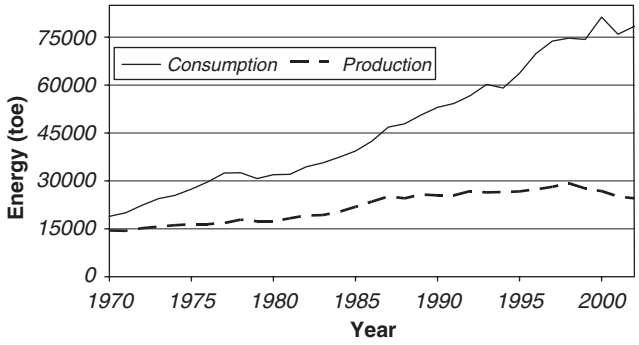

Fig. 2. Energy production and consumption in Turkey (Energy Statistics, 2003).

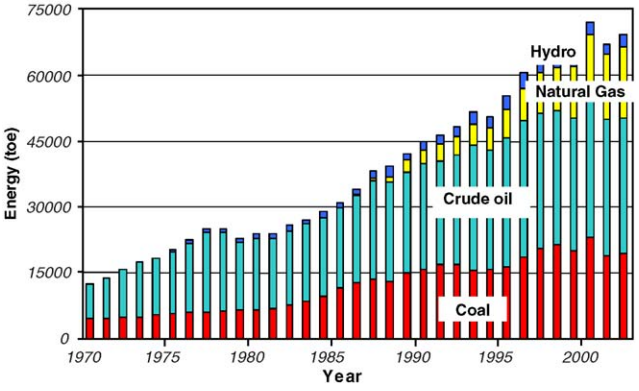

Fig. 3. Primary energy resources consumption of Turkey (Energy Statistics, 2003).

(38%) was due to the energy transformation (thermic plants) sector while the industry had a share of 28% in 2002 (SIS, 2003).

There are few studies that investigate the relationship between economic growth, energy consumption, and the environmental considerations around the world. Some of them investigated the relationship between energy demand, gross national product (GNP), the real energy prices, and the estimation of CO_2 emissions (Lester and Ninomiya, 2005), while some of them focused on the relationship between economic growth, energy consumption, and environmental considerations with recommendations for sustainable development (Zhidong, 2003).

As seen from literature, there is a strong relationship between GNP, energy use, and CO_2 emission in Turkey for years 1970–2003 (Fig. 1) (Energy Statistics, 2003; SIS, 2004; CBRT, 2004).

The objective of this study was to investigate and model the relationship between economic growth by means of GNP, energy consumption, and CO_2 emission and to present recommendations based on future estimates by considering the energy politics applied in last 30 years in Turkey. In addition, total energy consumption (TEC) and total CO_2 (TCO_2) emission models were developed to predict the energy consumption and CO_2 emission up to year 2015. The characteristics of the energy sector of Turkey, modeling techniques used in the study, and the results were given in following sections.

2. Energy sector in Turkey

A deficit between the production and the consumption of energy has always been reported in Turkey due to the population increase, economic growth, and the limited energy resources. Energy deficit is met by importing electricity and energy resources. The energy production and consumption in Turkey are depicted in Fig. 2.

Total energy production in this period increased by 70% and reached 24.7 mtoe while the consumption was 79 mtoe in 2003 with an increase rate of 415%. The share of the domestic energy production in TEC was 77% in 1970 and 31% in 2002. The increasing difference between the production and consumption means that the rate of energy import has been in an increasing trend (Energy Statistics, 2003).

The reason of the decrease in the production and the consumption of the energy could be attributed to the domestic economic recession. Regional and national economical problems can decrease the production in all sectors and this consequently results in a reduction in energy consumption. As seen in Fig. 1, decreases in energy consumption and CO_2 emission were observed when a decrease occurred in the GNP. For instance, in 1995, while the GNP decreased, energy consumption and CO_2 emission also declined (Fig. 1).

2.1. Energy resources

The energy sector is highly dependent on fossil resources in Turkey. The share of the fossil resources in TEC was 87.3% in 2002 (Energy Statistics, 2003). As depicted in Fig. 3, the main fossil resources are petroleum and coal. It is seen that natural gas use was markedly increased especially after year 1990.

The energy reserves of Turkey are summarized in Table 1. It can be seen that Turkey has a significant coal potential. This reserve is mostly used in thermic power

Table 1
Energy resources in Turkey (Energy Statistics, 2003)

Resources	Total
Non-renewables	
Coal (mt)	9201
Crude oil (mt)	39
Natural gas (billion m^3)	10.2
Nuclear resources (t)	
Natural uranium	9129
Thorium	380,000
Renewables	
Hydro power (TWh yr^{-1})	126.1
Wind (TWh yr^{-1})	400
Geothermal (MW yr^{-1})	35,600
Solar energy (mtoe yr^{-1})	35.2
Biomass (mtoe yr^{-1})	32

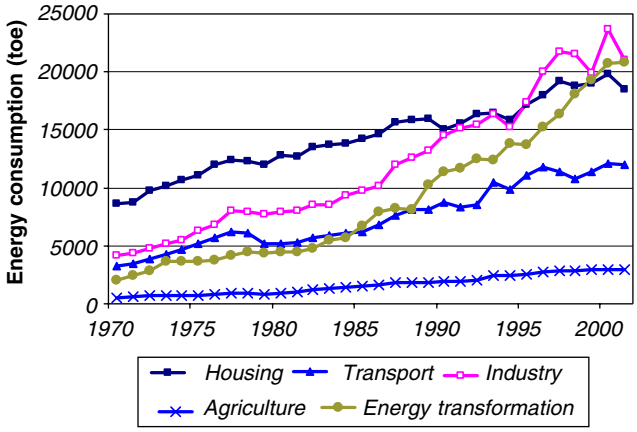

Fig. 4. Allocation of energy consumption for different sectors.

plants as fuel. About 90% of this reserve is low-calorie lignite. Lignite (81.5%) was consumed in thermic power plants in 2002 (Energy Statistics, 2003). It is also expected that the lignite reserves will be the major fuel in these power plants in future (Ünalan, 1994). On the other hand, Turkey has very limited oil and natural gas resources (Table 1). Because the consumption of oil and natural gas is significantly higher than the reserves, the import of these two energy inputs is increasing year by year. In addition, the use of natural gas in new thermic power plants established by using foreign capital is also a factor increasing its import rate.

Turkey has substantial reserves of renewable energy resources. These resources represented about 12.7% of total primary energy consumption. Renewable resources are the second-largest domestic energy source after coal. In Turkey, main renewable energy resources are hydro, biomass, wind, geothermal, and solar.

The economically usable hydropower potential of Turkey is 126.1 TWh yr^{-1}. However, only 25% of this potential is currently produced in hydropower plants.

Wind energy is fastest growing energy source in the world and wind power is one of the most widely used alternative energy sources today (Öztürk et al., 2005). It is estimated that the usable wind energy potential in Turkey at around 400 TWh yr^{-1}. Recently, use of wind energy has grown at an impressive rate in Turkey. The western coast and Southeastern Anatolia are very appropriate locations for wind power generations.

On the other hand, the country has the potential for 35.2 mtoe yr^{-1} solar energy, 35,600 MW yr^{-1} geothermal energy, and 32 mtoe yr^{-1} biomass energy. The actual utilization for the year 2002 is 318 toe for solar energy, 730 mtoe and 105 GWh for geothermal energy, and 21.2 mtoe for biomass energy.

Achieving sustainable development is a target that is now widely seen as important to worldwide public opinion. In this regard, the utilization of renewable energy resources appears to be one of the most efficient and effective ways in achieving this target (Öztürk et al., 2005).

2.2. Sectoral consumption

The temporal change of energy consumption for different sectors is depicted in Fig. 4 (Energy Statistics, 2003). The housing sector had the highest energy consumption until 1990. However, the share of the housing sector has gradually decreased after 1990. The housing sector consumed 45.9% of the total energy in 1970, on the other hand, its consumption decreased to 23.0% in 2002. Energy consumption in industry tends to increase in parallel to the economic growth. The share of this sector in the TEC increased from 21.8% in 1970 to 31.2% in 2002. The agricultural sector had a slightly increasing trend, however, its consumption has been the lowest compared to the other sectors (Fig. 4). The consumption share of this sector was 3.9% in 2002.

Energy transformation for the production of the electricity is also increasing year by year. This sector constitutes a significant portion in the total consumption (25% in 2002). When the energy politics are evaluated, it can be seen that the thermo power plants produce the majority of the electricity. In 2002, thermo plants produced 74% of the electricity while the share of hydraulic plants was 26%.

3. The models

As a beginning point, energy consumption as a function of the economic growth should be estimated to determine the relationship between economic growth, energy consumption, and CO_2 emission. For this purpose, a model that estimates the TEC based on GNP and country population (CP) was developed by using multi-linear regression analysis. TEC was predicted based on 6.7% annual increase in GNP, which was targeted in the last development plan. The annual data for the years from 1970 to 2002 were used in the analysis.

Secondly, the relationship between the energy consumption and the TCO_2 was modeled by using simple regression analysis. Also, the TCO_2 was calculated from intergovernmental panel on climate change (IPCC) method and the two results were compared.

3.1. Data sources

The data used in the development of the models were obtained in an annual basis from different governmental agencies:

- the data for TEC from the Energy Statistics (2003) and the Ministry of Energy and Natural Resources (MENR, 2004),
- CP data from the SIS (2004),
- the data for GNP that represents the economic changes from the Central Bank of the Republic of Turkey (CBRT, 2004), and
- the data for the CO_2 emission caused by energy production from the SIS (2003).

3.2. The model for the TEC

CP and the GNP data for the years from 1970 to 2002 were used in the regression analysis as independent variables using the SPSS statistics package to predict the TEC. The variables in the regression model were in the logarithmic format. The statistical results obtained from the regression analysis are given in Table 2.

As can be seen from Table 2, the TEC can be explained by CP and GNP with high accuracy ($R^2 = 0.996$). Although the results showed that the model developed in the analysis is promising in the projection of future TEC values for near term, the developed model was tested by using the data of previous years to predict the corresponding TEC values. The actual and predicted TEC values between 1970 and 2002 are compared in Fig. 5. It was observed that the predicted TEC data were very close to the actual ones.

It should be noted that to obtain successful future projections of TEC, the independent variables, CP and GNP, to be used in the prediction model have also to be precisely estimated.

3.3. The prediction of CP and GNP

In the prediction of CP, *the natural increase* formula recognized by the SIS was used:

$$P_n = P_o e^{rn}, \quad (2)$$

where P_n is the second of two consecutive censuses, P_o the first of two consecutive censuses, e the constant (2.7182818), r the rate of change of population within the specified unit of time between two censuses, and n the number of time units between the two censuses.

In the prediction of GNP, 6.7% annual economic growth increase, which was targeted in the last Development Plan published in 2000 (SPO, 2000), was used.

Table 3 gives the predicted CP and GNP values for 2010 and 2015. In addition, the TEC values predicted using the model developed earlier were given for the mentioned years (Table 3).

3.4. The model for the TCO_2 emission

A linear regression analysis between the TEC and TCO_2 data for the years 1970–2001 was performed in SPSS software. The results of the analysis are given in Table 4.

It was observed that the TCO_2 can be explained by TEC with high accuracy ($R^2 = 0.998$). The developed model was tested by using the data of previous years to predict the corresponding TCO_2 values. The actual and predicted TCO_2 values between 1970 and 2001 are compared in Fig. 6.

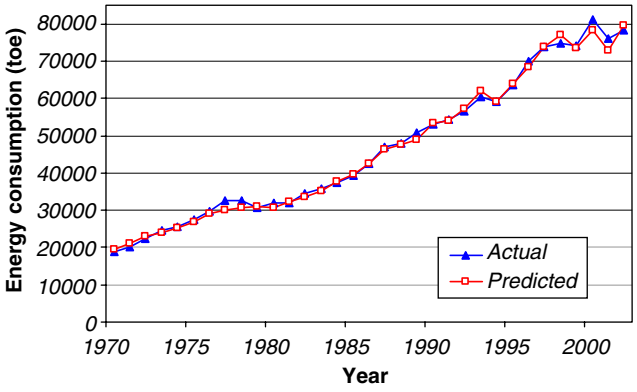

Fig. 5. Comparison of actual and predicted TEC values.

Table 2
Statistical results of the regression analysis for the TEC model

Independent variables	Coefficients	Standard error	"t"-Statistics	Significance level (P)
Intercept (constant)	−25.669	0.415	−61.796	0.001
ln(CP)	0.526	0.170	3.101	0.004
ln(GNP)	0.847	0.092	9.194	0.001

$$\ln(\text{TEC}) = -25.669 + 0.526 \ln(\text{CP}) + 0.847 \ln(\text{GNP}), \quad (1)$$

$R^2 = 0.996$, F-statistic = 4018.302, and $P = 0.001$.
TEC, total energy consumption (toe); CP, country population (person); GNP, gross national product (Turkish Lira (TL) in 1987 TL).

Table 3
Predicted CP, GNP, and TEC values for 2010 and 2015

	1970	1980	1990	2000	Predictions	
					2010	2015
CP (person)	35,605,179	44,736,957	56,473,035	67,844,903	81,506,703	89,337,002
GNP (Million TL. 1987)	34,469	50,870	84,592	119,144	198,979	275,187
TEC (mtoe)	18.92	31.98	52.99	81.26	133.19	183.95

Table 4
Statistical results of the regression analysis for the TCO_2 model

Independent variables	Coefficients	Standard error	"t"-Statistics	Significance level (P)
Intercept (constant)	−0.423	0.094	−4.477	0.000
ln(TEC)	1.121	0.009	126.405	0.000

$$\ln(TCO_2) = -0.423 + (1.121 \times \ln(TEC)), \quad (3)$$

$R^2 = 0.998$, F-statistic = 15,978.213, and $P = 0.000$.
TCO_2E, total CO_2 emission (Gg); TEC, total energy consumption (toe).

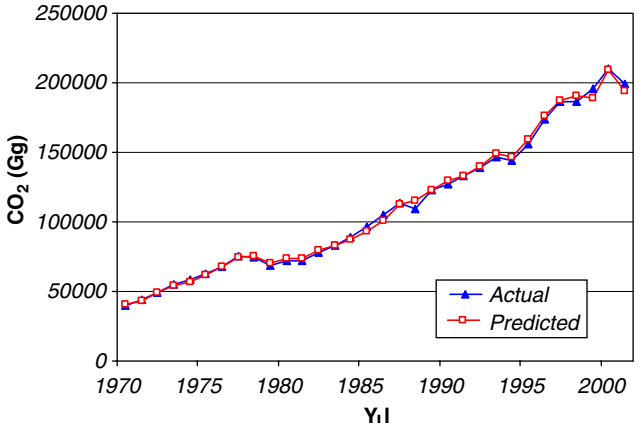

Fig. 6. Comparison of actual and predicted TCO_2 values.

3.5. Predicting the TCO_2 emission using the IPCC method

In the IPCC method, the TCO_2 is calculated by using the FC data and the properties of the fuel used in the energy production (IPCC, 1996):

$$TCO_2 = FC \times CC \times CEF \times OCR \times CO_2/C \times 0.001, \quad (4)$$

where TCO_2 is the total CO_2 emission (Gg), FC the fuel consumption (toe), CC the conversion coefficient ($41.868\,TJ\,toe^{-1}$), CEF the carbon emission factor ($t\,C\,TJ^{-1}$), OCR the oxidized carbon ratio, CO_2/C the ratio of the molecular weight of CO_2 to the atomic weight of carbon (44/12), and 0.001 the conversion coefficient from ton to Gg.

The CEF and OCR data according to the type of the fuel are given in Table 5.

Table 5
CEF and OCR values for different fuels (IPCC, 1996)

Fuel	Carbon emission factor (CEF)	Oxidized carbon ratio (OCR)
Hard coal	25.8	0.980
Lignite	27.6	0.980
LPG	17.2	0.995
Jet fuel	19.5	0.990
Fuel–oil	20.2	0.990
Oil	20.0	0.990
Natural gas	15.3	0.995
Other oil products	20.2	0.990

In Turkey, the institution that calculates and publishes the greenhouse emission data according to the IPCC method is the SIS. The data regarding the FC for Eq. (4) are obtained from the Energy Balance Sheets prepared by the MENR of Turkey. Therefore, the predictions regarding the FC that will be used in the calculations were obtained from the data prepared by the MENR.

4. Conclusions

The CO_2 emission values predicted using the IPCC method and the TCO_2 model are given in Table 6 for 2010 and 2015.

When the predicted TCO_2 values obtained from the two methods were compared, it was seen that the values predicted by IPCC method were noticeably higher. For instance, for the year 2010, the TCO_2 predicted by the IPCC method was 480,244 Gg while the one obtained by the TCO_2 model developed in this study was 363,769 Gg (Table 6).

The most important reason of this difference is attributed to MENR's estimation of the FC values which were observed to be markedly higher than the actual values. For example, the actual energy consumption was 78,403 btoe for the year 2002. However, this was predicted as 109,035 btep by the MENR in 1998. Another example is that the coal consumption prediction of the MENR calculated in 1998 was 26,842 btep for the year 2002 while the actual consumption was 19,473 btep. Realistic estimation of the greenhouse emissions gained more importance, especially after Turkey became a party to the Framework Convention on Climate Change on 18 December 2003, because being a party to this convention brings more responsibilities. Therefore, better predictions and plans need to be put into practice to meet the responsibilities of the convention.

The method that is accepted worldwide for the calculation of the greenhouse emissions is the IPCC method. In Turkey, the main responsible institution is the MENR for these calculations. The predictions of the energy consumption should be as close as possible to the actual values. However, in Turkey conditions, the prediction of these values seen to be higher than the actual ones due to political and economical reasons is an important topic discussed in different platforms (CEE, 2003).

Energy is vital and one of the pivotal inputs which affects the economical and social development. While energy consumption is inevitably expanding in parallel to the increasing population, industrialization, and prosperity level, efficient ways of energy use should be investigated. One of the most important tasks from the point of sustainability is to decouple the economic growth from the environmental impact. Therefore, minimum energy consumption with least cost, which results in least detrimental effect on the environment and also promotes the economic and social development, should be achieved by considering sustainable development principles.

After evaluating the energy sector in Turkey and future predictions, the following findings were obtained:

- Turkey contributes to the global CO_2 emissions with a share of 0.9%. It is expected that the energy consumption and CO_2 emissions in Turkey will continue to increase as a result of the energy politics implemented in the past and planned for the future.
- TEC (95%) is obtained from the fossil resources in Turkey. The thermic power plants are the most common in the energy production systems. There are 32 thermal power plants with a total capacity of 19,568.3 MW. Some of these plants utilize low-calorie domestic lignite. These plants are an important source of the TCO_2 emissions in Turkey with 38% share.
- The lignite, which is also used in significant amounts in Turkey, causes the highest CO_2 emission. The

Table 6
Predicted TCO_2 (Gg) for 2010 and 2015 from the IPCC method and the TCO_2 model

	1970	1980	1990	2000	Predictions	
					2010	2015
TCO_2 (IPCC method)	39,742	72,005	127,174	210,462	480,244	631,781
TCO_2 (TCO_2 model)					363,769	522,427

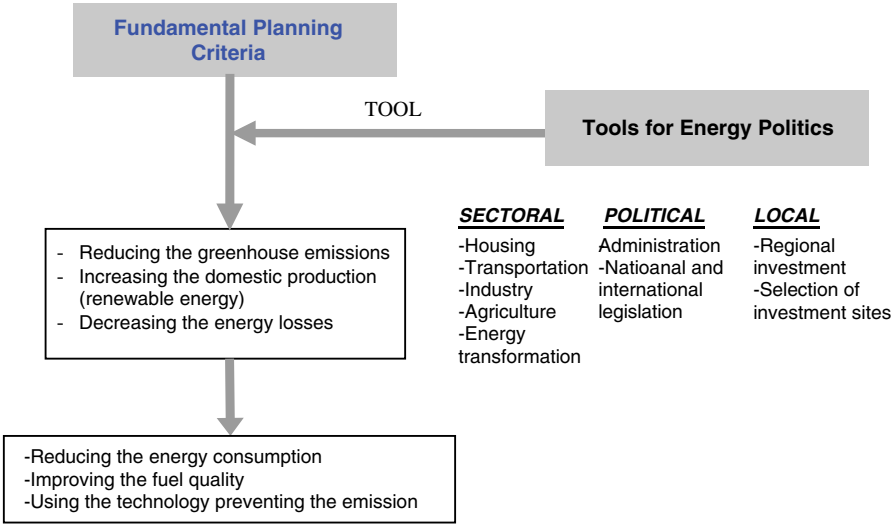

Fig. 7. Fundamental political and planning criterions for energy sector.

hydraulic energy production systems are the cleanest energy source since they have the lowest CO_2 emission. Although Turkey has a great hydraulic potential, it uses only 25% of this potential (Energy Statistics, 2003).

- An 8.4% increase in energy consumption is expected as a result of the population increase and the 6.7% economic growth expected in the upcoming years in Turkey. Also, it is expected that this increase in the energy consumption will increase the CO_2 emission by 9.9% yearly in average.

The fundamental political and planning criterions can be evaluated under three topics as depicted in Fig. 7 according to the findings mentioned above.

(a) *Reducing the greenhouse emissions*: It is expected that the CO_2 emission will increase by 49% from 2000 to 2015. This increase should be evaluated as a reference for reducing the greenhouse emission to meet the conditions of the Framework Convention on Climate Change.
(b) *Increasing the domestic production*: Renewable energy sources should be utilized as much as possible.
(c) *Reducing the energy losses*: Since it is difficult to reduce the energy consumption in developing countries like Turkey, preventing the losses of transportation and distribution (30%) can be considered as an important benefit (Arıkan, 2003).

These criterions will be the basis for energy politics and plans by considering the "other sectors", "political concerns" regarding the energy sector, and "plans and its applications in local scale" explained in Fig. 7.

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