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Abstract. External costs that occur in the use of energy resources are one of the most important criteria in determining energy and environmental policies. For this purpose, it is important to know the external costs of any energy sources. The purpose of this study is to calculate external costs due to air pollutants in Turkey for the years 2000 and 2019. The air pollutants namely ammonia, nonmethane volatile organic compounds, nitrogen oxides, particulate matter, and sulphur dioxide have been taken into consideration in the evaluation for the impact categories-human health damage, loss of biodiversity, crop losses, and buildings damaged. These pollutant emissions data were obtained from the European Environmental Agency database. Then, these pollutant emissions data were used in the monetization calculations for the years 2000 and 2019. According to the evaluation, air pollutant emissions' total external costs in Turkey were 25135,72 Million Euros and 24654,42 Million Euros for the years 2000 and 2019 respectively.
Keywords: External cost; Pollutant emissions; CASES; EEA; Turkey

1. Introduction

The important factor for economic and social development is energy. Energy consumption is also increasing due to increasing population, urbanization, industrialization and widespread use of technology. On the other hand, the negative effects of energy resources on the environment during production and consumption are an important cost factor. For these reasons, energy production and consumption should be aimed at supporting economic and social development, compatible with the environment, high efficiency and cost-effectiveness. In accordance with this purpose, energy consumption should be kept at the lowest level possible and also energy should be consumed in the most economical and efficient way by considering the ecosystem.

From the extraction of energy resources to their use of various air pollutants are produced and spread to the environment, causing significant health and environmental effects. On a global scale, mainly energy usage is responsible for air pollution such as local acid rain and global climate change [1]. For this reason, the effect of air pollution on the ecosystem should be taken into account.

Energy systems generate air pollutants that damage building materials, biodiversity and human health when they are in operation. These results are produced by external costs [2-3].

Cost Assessment for Sustainable Energy Systems (CASES) project has been developed to calculate electricity generation external costs in European Union countries and also other countries [4].

In the literature, there are various studies carried out using the external costs given in the CASES project.

Streimikiene et al., (2009) have calculated electricity generation external costs in Baltic States. And they have been compared the calculated results for the Baltic States [5].

In another study, In Lithuania's electricity generation, external costs were investigated in the 2010-2030 time period, taking into account the life cycle stages in electricity generation technologies [6].

Streimikiene and Mikalauskas, (2015) have reviewed and compared atmospheric pollution external costs and pollution taxes in Lithuania and Poland and the policy recommendations are suggested according to the evaluated results [7].

And Köne, (2015) have been investigated the pollutant emissions external cost for several Selected Nomenclature for reporting of Air Pollutants (SNAP) sectors in Turkey for the years 2000 and 2010 for air pollutants, which are ammonia (NH_3), nonmethane volatile organic compounds (NMVOC), nitrogen

oxides (NO_x), particulate matter ($PM_{2.5}$), particulate matter (PM_{10}) and sulphur dioxide (SO_2). The calculated results were evaluated in terms of sustainable energy use [8].

The aim of this paper is to calculate emitted air pollutants' external costs in Turkey for the years 2000 and 2019.

2. Methods

The external costs for air pollutants NH_3, NMVOC, NO_x, $PM_{2.5}$ PM_{10} and SO_2 due to an average height of release were calculated by using the CASES project depending on the EcoSense model for various heights of pollutant emissions [9]. The calculated results were based on the parameterized results of a complex distribution model. Air pollutant effects on human health, crops, materials and biodiversity losses caused by acidification and eutrophication were considered in the EcoSense model.

The air pollutants' external costs for Turkey with respect to the impact categories were obtained from the CASES project database [10]. Those values are presented in Table 1. As one can see from Table 1 some external costs are negative. This means that the emissions of NMVOC have a positive impact on biodiversity and human health. Similarly, emissions of NH_3 have positive impacts on crops [6].

Data for Air pollutant emissions in Turkey were taken from the European Environmental Agency database [11]. The data were given in Table 2. According to Table 2, the sources of NO_x emissions were mainly energy production and distribution, energy use in industry, commercial, institutional and households and road transport sectors for the study years. The two main sectors of SO_2 emissions were energy production and distribution and energy use in industry sectors for both 2000 and 2019. PM_{10} emissions mostly came from the industrial processes and commercial, institutional and households for the years 2000 and 2019. Industrial processes were responsible for $PM_{2.5}$ emissions for the years 2000 and 2019. The two main sectors of NMVOC emissions were agriculture and industrial processes sectors for both 2000 and 2019. NH_3 emissions mainly came from the agriculture sector for the years 2000 and 2019.

Air pollutant emissions external costs in Turkey for the years 2000 and 2019 were calculated by using the data provided in Table 1 and Table 2.

The calculated external costs due to pollutant types and impact categories were presented in Table 3. The total external costs by impact categories and pollutant types were also presented in Table 4 and Table 5 respectively.

3. Results and Discussion

As seen in Table 3, according to the 2000 and 2019 results, the total external costs due to the air pollutant in Turkey were approximately the same. The total external costs due to the pollutant emissions in Turkey were calculated as 25135,72 Million Euros and 24654,42 Million Euros for the years 2000 and 2019 respectively (see Table 3).

The extremely higher external cost was calculated in the human health impact category according to the other impact categories (see Table 4). And the extremely higher external cost was calculated for SO_2 emissions according to the other pollutant emissions (see Table 5). As seen in Table 4 and Table 5, the results for the total external costs by the impact categories and the air pollutant types were approximately the same values for the years 2000 and 2019.

The SO_2 emissions are the dominant pollutant according to the calculated external costs (see Table 5). So, Turkey should reduce SO_2 emissions in the future for the purpose of decreasing external costs due to SO_2 emissions.

Between 2000-2019, Turkey's electrical energy production reached 304 TWh with an increase of 143%. The share of fossil fuel use in electrical energy production, which was 75% in 2000, decreased to 56% in 2019. The share of renewable energy in electricity production (wind, PV, geothermal), which had very low in 2000. And it reached approximately 13% in 2019. The biggest contribution to this share was realized by wind energy. The same increase rates especially in the use of solar PV and geothermal

energy in total electricity production will make a significant contribution to the reduction of air pollutant emissions in Turkey. The share of fuel types used in electricity production is given in Table 6 [12],

In Turkey, in order to reduce emissions of air pollutants, especially SO_2 and NOx, the use of fossil fuels is reduced in the total primary energy supply as well as electrical energy in the future, while the rate of increase in the use of wind energy should especially be reflected in the use of PV.

According to results obtained in this study, the usage of renewable energy in the total primary energy supply of Turkey must be increased to decrease the air pollutant emissions' external costs.

Table 1. External costs for the air pollutants released in Turkey.

Effect type of pollutants	Cost (Euro 2000/tonnes)
Human health impact	
NH_3	5194
NMVOC	-33
NO_x	2780
PM_{10}	862
$PM_{2.5}$	19725
SO_2	5337
Loss of biodiversity	
NH_3	607
NMVOC	-6
NO_x	102
SO_2	2
Impact on crops	
NH_3	-34
NMVOC	9
NO_x	44
Impact on materials	
NO_x	71
SO_2	259

Table 2. Total air pollutant emissions in Turkey (Gg).

Pollutant	2000	2019
NH_3	640,2	764,7
NMVOC	1607,5	1120,7
NO_x	1492	779
PM_{10}	320,7	249
$PM_{2.5}$	212,2	202,2
SO_2	2242,3	2454,5

Table 3. External costs due to air pollutant types and impact categories (M Euro 2000).

Effect type of pollutants	2000	2019
Human health impact		
NH_3	3325,20	3971,85
NMVOC	-53,05	-36,98
NO_x	4147,76	2165,62
PM_{10}	276,44	214,64
$PM_{2.5}$	4191,56	3988,40
SO_2	11967,16	13099,67
Loss of biodiversity		
NH_3	388,60	464,17
NMVOC	-9,65	-6,72
NO_x	152,18	79,46
SO_2	4,48	4,91
Impact on crops		
NH_3	-21,77	-26,00
NMVOC	14,47	10,09
NO_x	65,65	34,28
Impact on materials		
NO_x	105,93	55,31
SO_2	580,76	635,72
Total	**25135,72**	**24654,42**

Table 4. Total external costs by impact categories (M Euro 2000).

Effect type	2000	2019
Human health	23855,07	23403,20
Loss of biodiversity	535,61	541,82
Impact on crops	58,35	18,37
Impact on materials	686,69	691,03

Table 5. Total external costs by air pollutant types (M Euro 2000).

Pollutant	2000	2019
NH_3	3692,03	4410,02
NMVOC	-48,23	-33,61
NO_x	4471,52	2334,67
PM_{10}	276,44	214,64
$PM_{2.5}$	4191,56	3988,4
SO_2	12552,4	13740,30

Table 6. The fuel shares in the total electricity production of Turkey (%)

Fuel type	2000	2019
Coal	30,57	37,15
Oil	7,45	0,11
Natural gas	37,00	18,85
Biofuels	0,13	1,15
Waste	0,01	0,01
Hydro	24,72	29,23
Geothermal	0,06	2,95
Solar PV	0,00	3,04
Wind	0,03	7,15
Other sources	0,04	0,36

4. Conclusions

This paper estimates the environmental external costs due to total air pollutant emissions in Turkey for the years 2000 and 2019. The estimation results show that the external costs were 25135,72 Million Euros and 24654,42 Million Euros for the years 2000 and 2019 respectively. This means that Turkey did not decrease its air pollutant emissions in this period.

Sustainable development, which has economic, social and environmental dimensions, requires the integration of all economic and social policies of a country with its environmental policies and strategies.

According to the above calculation results, in order to achieve sustainable development goals, Turkey has to reduce its air pollutant emissions. In this sense, the following policy recommendations can be listed for decision-makers:

- The large power plants' emissions standards should be aligned with the EU legislation [13],
- In the near future, the renewable energy source percentages should be increased in electricity production. To achieve this, the economic positive impacts will be important when investing in renewable energy sources technologies [14].
- As in the European Union [15], renewable energy cooperatives should be supported by local and central authorities in order to increase renewable energy electricity generation.
- In all energy investments, the principle should be to minimize the air pollutant emissions to the environment. For this purpose, all preventions to reduce emissions in the thermal power plants should be immediately taken.
- Turkey's energy policies should be renewed in line with the aim of using local and renewable energy sources.

In future studies, external costs of air pollutants will also be evaluated according to sectors when Turkey's sectoral air pollutant data are available [16].

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