COBENEFITS STUDY

October 2020

Improving people's health and unburdening the health system through renewable energy in Turkey

Assessing the co-benefits of decarbonising the power sector

Executive report

İPM | IPC İSTANBUL POLİTİKALAR MERKEZİ SABANCI ÜNİVERSİTESİ ISTANBUL POLICY CENTER SABANCI UNIVERSITY

IASS POTSDAM

IET International Energy Transition

COBENEFITS

This study has been realised in the context of the project "Mobilising the Co-Benefits of Climate Change Mitigation through Capacity Building among Public Policy Institutions" (COBENEFITS).

This project is part of the International Climate Initiative (IKI). The Federal Ministry for the Environment, Nature Conservation, and Nuclear Safety (BMU) supports this initiative on the basis of a decision adopted by the German Bundestag. The COBENEFITS project is coordinated by the Institute for Advanced Sustainability Studies (IASS, lead) in partnership with the Renewables Academy (RENAC), the Independent Institute for Environmental Issues (UfU), International Energy Transition GmbH (IET), and in Turkey the Sabanci University Istanbul Policy Center (IPC).

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INTERNATIONAL CLIMATE INITIATIVE (IKI)

Reviving Turkey's public health and unburdening the health system

Foreword in light of the COVID-19 pandemic

At the time this report is being published, Turkey along with many economies around the world has been severely affected by the spread and impacts of the global COVID-19 pandemic. Similarly to many countries worldwide, the Turkish economy, along with thousands of businesses and workers, has been deeply affected, and substantial political efforts will be needed to rebuild national and local economies and job markets. The pandemic also reminded us how public health measures are equally important as a strong and resilient health system.

This report and the related COBENEFITS study series for Turkey suggest that the new energy world of renewables and the decarbonisation of Turkey's energy sector should have a strong role in reviving the economy and health system by boosting employment, fostering energy independence as a foundation of economic resilience, and — importantly — unburdening national health systems by reducing the incidence of respiratory diseases. By providing the enabling policy environment necessary for unlocking these co-benefits, the Government of Turkey can provide important stimuli to recover from the impacts of the COVID-19 pandemic and revive both the health system and the national economy.

Turkey is in the midst of an energy transition, with important social and economic implications, depending on the pathways that are chosen. Independence from energy imports; economic prosperity; business and employment opportunities as well as people's health: through its energy pathway, Turkey will define the basis for its future development. Political decisions on Turkey's energy future link the missions and mandates of many government ministries beyond energy, such as environment, industrial development, economics, foreign relations, and health.

Importantly, the whole debate boils down to a single question: How can renewables improve the lives and wellbeing of the people of Turkey? Substantiated by scientific rigor and key technical data, the study at hand contributes to answering this question. It also provides guidance to government ministries and agencies on further shaping and enabling the political environment to unlock the social and economic co-benefits of the new energy world of renewables for the people of Turkey.

Under their shared responsibility, the Istanbul Policy Center (IPC) of Sabanci University (as the COBENEFITS Turkey Focal Point) and IASS Potsdam invited the ministries of Energy and Natural Resources (MoENR), Environment and Urban Affairs (MoEU), Treasury and Finance (MoTF, formerly Ministry of Economics MoE), Foreign Affairs (MoFA), and Health (MoH) to contribute to the COBENEFITS Council Turkey and to guide the COBENEFITS Assessment studies along with the COBENEFITS Training programme and *Enabling Policy* roundtables. Their contributions during the COBENEFITS Council sessions guided the project team to frame the topics of the COBENEFITS Assessment for Turkey and to ensure their direct connection to the current political deliberations and policy frameworks of their respective departments.

We are also indebted to our highly valued research and knowledge partners, for their unwavering commitment and dedicated work on the technical implementation of this study. The COBENEFITS study at hand has been facilitated through financial support from the International Climate Initiative of Germany. The Government of Turkey has emphasised climate change as one of the most significant problems facing humanity, presenting wide-ranging threats to Turkey's future unless early response measures are taken. Within the scope of Turkey's National Climate Change Strategy, the government has laid out its vision for providing citizens with high quality of life and welfare standards, combined with low carbon intensity.

With this study, we seek to contribute to this vision by offering a scientific basis for harnessing the social and economic co-benefits of achieving a just transition to a low-carbon, climate-resilient economy and thereby also allowing Turkey to achieve a regional and international front-runner role in shaping the new low-carbon energy world of renewables, making it a success for the planet and the people of Turkey.

We wish the reader inspiration for the important debate on a just, prosperous, and sustainable energy future for Turkey!

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Executive Summary

COBENEFITS

Improving people's health and unburdening Turkey's health system through renewable energy in Turkey
Assessing the co-benefits of decarbonising the power sector

Coal- and natural gas-fired power plants in Turkey are significant sources of atmospheric emissions that are harmful to people's health and the environment. This study analyses the impacts of the pollutants CO, SO_2, NO_2, and PM10 on human health. Turkey's need for electricity will continue to increase in the coming years. Recognising that coal- and natural gas-fired electricity generation are major contributors to atmospheric pollutants and related health impacts, it is evident that an increased share of renewable energy in electricity generation would help lessen the problems of air pollution and reduce costs for the Turkish health system.

This study assesses the impacts of fossil-fuel power plants in Turkey on people's health. It quantifies the co-benefits[1] of decarbonising Turkey's power sector with renewable energy for unburdening Turkey's health system, in terms of health cost savings and reduction in premature deaths. This research study has been carried out in the context of the COBENEFITS project, which assesses a range of socio-economic co-benefits of renewable energy, in addition to the benefits of reducing energy sector greenhouse gas emissions, when compared to conventional energy systems.

COBENEFITS
Securing Turkey's energy supply and balancing the current account deficit through renewable energy Assessing the co-benefits of decarbonising the power sector

available on www.cobenefits.info

KEY POLICY OPPORTUNITIES

- **Policy opportunity 1:** Turkey can significantly reduce the number of premature deaths related to air pollution from fossil-fuelled power plants. Under the current policy, mortality can be expected to increase from 2,100 cases in 2017 to more than 2,300 cases in 2028. By following an ambitious decarbonisation pathway (Advanced Renewables Scenario B), estimated mortality would be reduced to less than 1,600 cases in 2028, thus avoiding more than 750 deaths in that year alone.

- **Policy opportunity 2:** Turkey can significantly unburden its health system by decarbonising the power sector: Under the current policy, annual health-related costs[2] can be expected to increase from USD 2.15 billion in 2017 to USD 2.5 billion in 2028. By following an ambitious decarbonisation pathway (Advanced Renewables Scenario B), health cost savings in 2028 can amount to USD 800 million in this year alone.

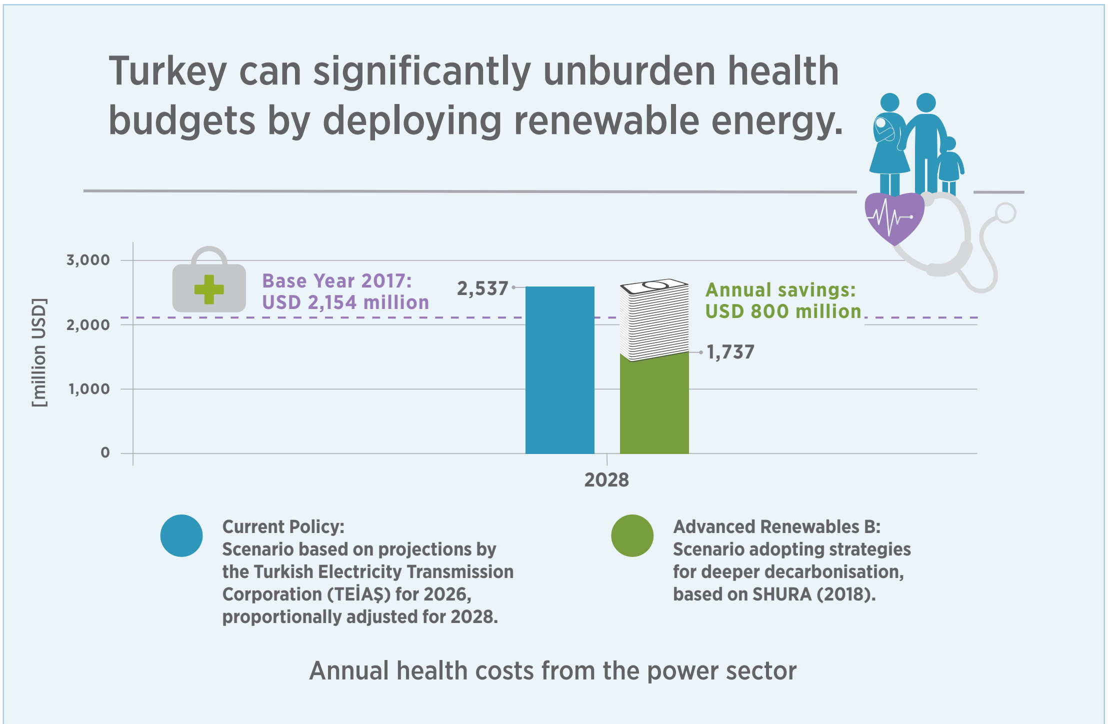
- **Policy opportunity 3:** The Ministry of Energy can support measures to track progress in reducing health impacts and related health costs by ensuring access to air pollutant emission data from individual power plants, detailing the relevant fuel, technological, and emission control standards. Public monitoring and technical analysis of power plants can improve the quality and reliability of air pollution and health cost assessments. This can be facilitated by public access to technical data on thermal power plants, such as filtration methods, combustion techniques, water consumption, fuel usage, and atmospheric pollution releases.

[1] The term 'co-benefits' refers to simultaneously meeting several interests or objectives resulting from a political intervention, private-sector investment or a mix thereof (Helgenberger et al., 2019).

[2] Health-related costs in the underlying model have been calculated in Euro. In view of international comparability these values have been converted to USD, based on the official exchange rate as of 01.07.2020.

KEY FINDINGS:

- The highest SO_2 concentrations are observed at the Edirne – Keşan, Amasya – Suluova, and Çorum – Mimar Sinan stations. The highest NO_2 concentrations are observed at the Ordu – Ünye, Samsun – Yüzüncüyıl, and Kayseri – Hürriyet stations. Hourly CO concentrations are high at some locations, in some instances more than 10 times the Turkish air quality standards.
- Annual PM_{10} concentration (averaged over all available air quality stations) is 54 µg/m³, breaching the air quality standard of 40 µg/m³ and clearly revealing that the air pollutant of greatest concern in Turkey is PM_{10}. The highest PM_{10} concentrations are observed at Iğdır, Kahramanmaraş – Elbistan, and Ankara – Kayaş.
- The number of restricted activity days can be reduced by 18,100 days in 2028, thus improving Turkey's economic output.
- Turkey can significantly reduce the number of premature deaths related to air pollution from fossil-fuelled power plants, preventing more than 750 deaths in the year 2028. This calculation is based on YOLL (years of life lost) data relating to the effects of CO, SO_2, NO_2, and PM_{10}.
- Turkey can generate significant health cost savings, amounting to USD 800 million in 2028 alone. These cost savings result from reduced morbidity (chronic bronchitis, congestive heart failure, lung cancer) and mortality and from fewer hospital admissions and asthma cases.



Key figure 1: Turkey can significantly unburden health budgets by deploying renewable energy.

Source: own

KEY FIGURES:

- Annual health cost savings can amount to USD 800 million in the year 2028 alone.
- Asthma among children younger than 14 years can be reduced by almost 1 million cases in 2028.
- 750 premature deaths can be avoided in the year 2028 by increasing the share of renewables in the power sector.

		2017 Base Year	2028 Current Policy	2028 New Policy	2028 Advanced Renewables A	2028 Advanced Renewables B
Health Effects	**Mortality (cases)**	2,103	2,333	2,042	1,892	1,564
Health Costs	**Annual Health costs (USD million),** *through mortality, morbidity and hospital admissions*	2,154	2,537	2,241	2,084	1,737

Table ES.1: Health benefits and health cost savings under different energy scenarios

Source: own

FOUR POWER SYSTEM PATHWAYS FOR TURKEY

The co-benefits assessment for Turkey takes a policy-directed scenario approach, to connect with existing policy environments and learn from comparing the socioeconomic performance of various potential energy transition pathways in Turkey. In consultation with government and expert organisations, four scenarios were defined to assess the socio-economic implications of increasing the share of renewable energy in Turkey's future electricity generation mix in the year 2028 (see Figure ES.1): Building on the base year (2017) for this study, the four scenarios project an increase of total generation by a third from around 300 TWh (2017) to around 400 TWh (2028).

1. **Base year (2017):** For the base year of the study the Turkish Electricity Transmission Corporation (TEİAŞ) reported 30.3 GW renewable energy installed capacity with a total generation of 68.0 TWh, accounting for 23% of total power generation[3].

2. **Current Policy Scenario:** Based on projections by the Turkish Electricity Transmission Corporation (TEİAŞ) for 2026, proportionally adjusted for 2028. Under this scenario, in 2028 renewable energy installed capacity amounts to 61.5 GW, with a total generation of 142.0 TWh, accounting for 36% of total power generation.

3. **New Policy Scenario:** Based on the Ministry of Energy and Natural Resources (MoENR) announcements of 1 GW annual increase in solar and wind capacity for 10 years, starting in 2018, as a part of its "National Energy and Mining Policy" (MoENR, n.d.). Under this scenario, in 2028 renewable energy installed capacity amounts to 69.5 GW, with a total generation of 167.1 TWh, accounting for 43% of total power generation.

[3] The energy sources used to calculate the generation shares in this report cover 99% of the power generated in the base year 2017. When including the remaining energy sources such as diesel or biomass, the rounded percentage of renewable energy sources (23% for 2017) would remain unchanged. Hence, no major discrepancies are expected for the 2028 target year.

4. **Advanced Renewables Scenario A:** Under this scenario, in 2028 renewable energy installed capacity amounts to 77.5 GW, with a total generation of 181.5 TWh, accounting for 46 % of total power generation. This scenario is based on a report by SHURA (2018), which concluded that increasing installed wind and solar capacities to 20 GW each is feasible without any additional investment in the transmission system.

5. **Advanced Renewables Scenario B:** Under this scenario, in 2028 renewable energy installed capacity amounts to 97.5 GW, with a total generation of 217.0 TWh, accounting for 55 % of total power generation. This scenario is based on the same report by SHURA (2018), which concluded that increasing the solar and wind sector to 30 GW each is possible under the condition of a 30 % increase in transmission capacity investment and 20 % increase in transformer substations investment.

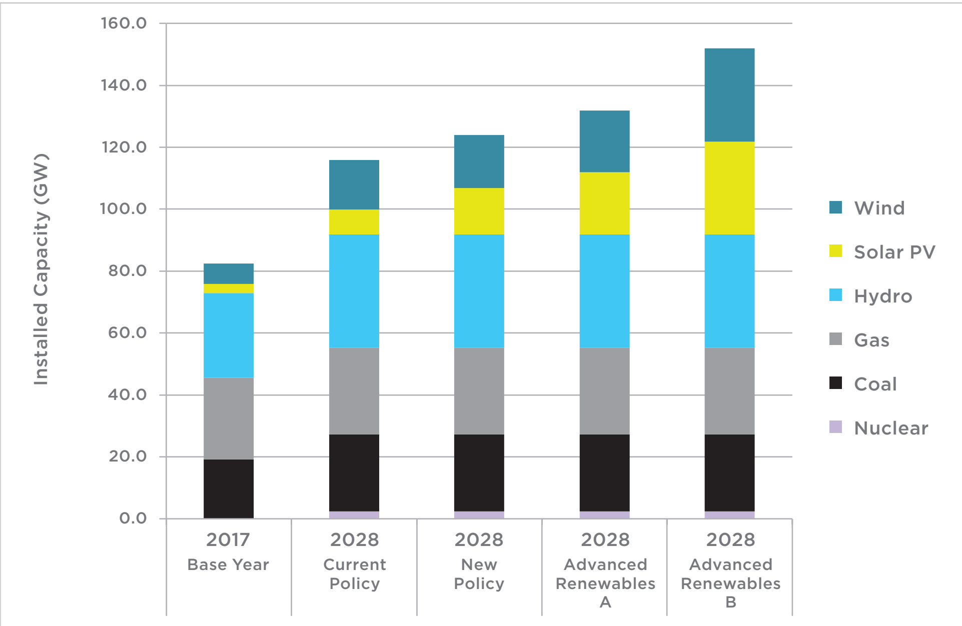


Figure ES.1: Electricity generation capacity projections under different scenarios

Source: own

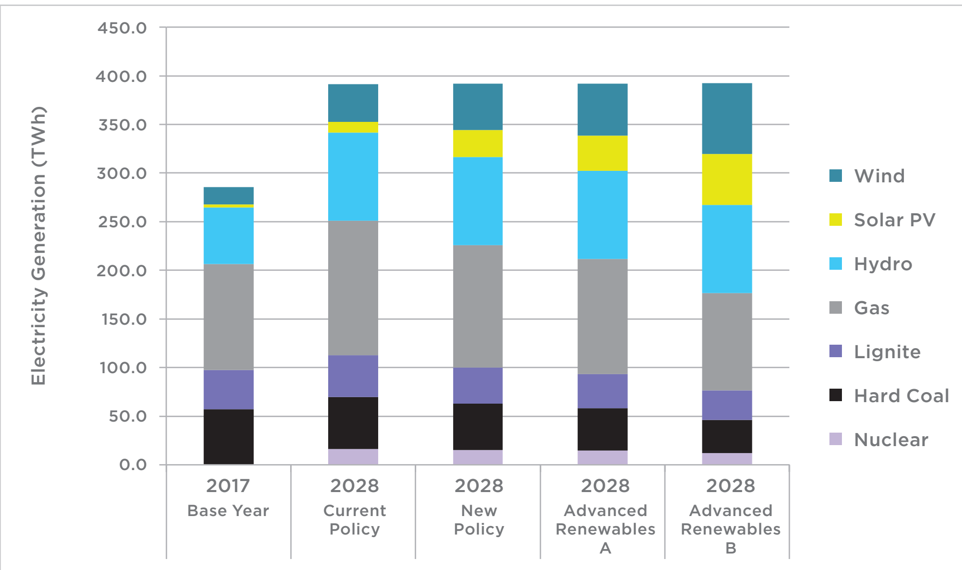


Figure ES.2: Electricity generation scenarios for different fuel types (TWh)

Source: own

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1. The status quo: health risks from air pollution in Turkey

Fossil fuel power plants are significant sources of atmospheric emissions that are harmful to human health and the environment. Emissions from coal- and natural gas-fired power plants commonly include acidifying gases such as sulphur dioxide (SO_2), nitrogen oxides (NO_x), and carbon monoxide (CO), along with particulate matter (PM), especially that with diameters smaller than 10 and 2.5 µm (PM_{10} and $PM_{2.5}$ respectively).

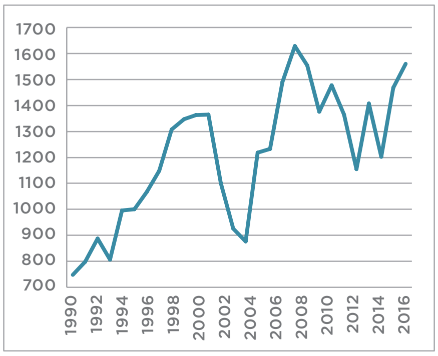
The World Health Organization (WHO) estimates that indoor and outdoor air pollution is responsible for about 7 million premature deaths annually at the global level (WHO, 2020). In a recent Lancet report (EEA, 2019), it is further reported that fuel combustion accounts for 85% of airborne PM pollution and almost all of the sulphur and nitrogen oxides. The US Environmental Protection Agency reports that electricity-producing power plants cause more hazardous air pollution than any other industrial activity. The WHO also estimates that ambient air pollution in Turkey causes 36,698 premature deaths annually (WHO, 2018).

Turkey's electricity demand will continue to increase rapidly in the next decade. Recognising that coal- and natural gas-fired electricity generation are major contributors to atmospheric pollutants, it is evident that increasing use of renewables for electricity generation will lessen this problem. This report assesses the potential improvements in air quality and human health due to an increased share of renewable energy in Turkey's electricity generation mix.

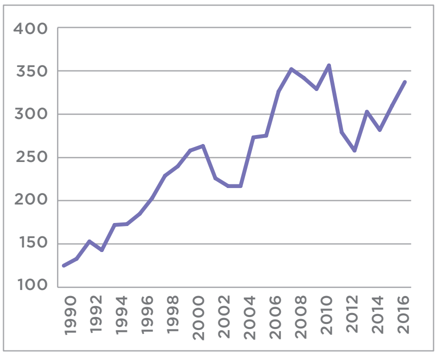
1.1 Increasing risks from air pollution

According to Turkey's CLRTAP (Convention on Long-Range Transboundary Air Pollution) reporting in 2019 (EEA, 2019), air pollutant emissions, especially SO_x and NO_x, from the energy sector (e.g., public electricity and heat production, petroleum refining, and manufacture of solid fuels and other energy industries) have increased since 2014 (Figure 1). Based on Turkey's 2019 inventory report under CLRTAP, primary emissions from electricity and heat production are SO_x and NO_x; emissions from road transportation are NOx and PM_{10}; those from agriculture are NH_3 and NMVOCs, while PM10 is the primary air pollutant emission from chemical industries.

However, as Turkey is not a signatory to the Gothenburg Protocol, emissions solely from electricity production are not reported. Nonetheless, according to the International Energy Agency's (IEA) Energy and Air Pollution report of 2016, the energy sector is by far the largest source of air pollution emissions globally, particularly SO_2. As fossil fuel-based electricity production is a main driver of air pollution, reducing the share of fossil fuels in the electricity generation mix is also expected to lead to improved air quality.



(a) Sulfur oxides (SO_x, such as SO_2) emissions – in kilo tonnes per year (kt/a)

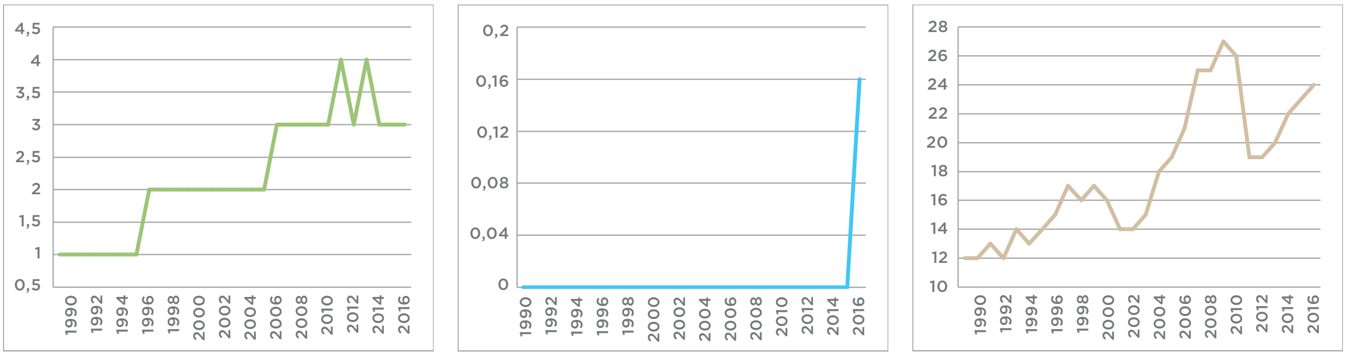


b) Nitrogen oxides (NO_X, such as NO_2) emissions (kt/a)

Figure 1a–e: Turkey's emissions from energy industries (electricity and heat combined).

Data source: EEA, 2019

Figure 1a–e (continued)



c) Non-methane volatile organic compounds (NMVOC) emissions (kt/a)

(d) Ammonia (NH_3) emissions (kt/a)

(e) Particulate matter (PM_{10}) emissions (kt/a)

1.2 Air quality standards

In 2008, Turkey adopted new air quality standards that are in line with European Union (EU) legislation (see Table 1). The standards for various pollutants are defined by exposure times, ranging from one hour to annual. It is important to note that the Turkish Regulations allow 18 exceedances per year for hourly NO2 concentration, 35 exceedances per year for 24-hour PM_{10}, 24 exceedances per year for hourly SO_2, and 3 exceedances per year for 24-hour SO_2 concentrations.

Table 1: Turkish, EU and WHO regulations for SO_2, NO_2, and PM_{10}

Source: own

Pollutant	Concentration (µg/m³)			
	Exposure period	Turkish Regulation[5]	EU Regulation 2008/50/EC	WHO (2006)
Sulphur Dioxide (SO_2)	1-hour[1]	350 by 01-2019; 410 in 2017	350	
	24-hour[2]	125	125	
	Annual	20		20
Nitrogen Dioxide (NO_2)	1-hour[3]	200 by 01-2024; 270 in 2017	200	200
	Annual	40	40	40
Particulate Matter (PM_{10})	24-hour[4]	50 by 01-2019; 70 in 2017	50	50
	Annual	40 by 01-2019; 48 in 2017	40	20
Carbon Monoxide (CO)	All times (1-hour, 8-hour, and Annual)	10,000	10,000	10,000

[1] Can be exceeded up to 24 times per year
[2] Can be exceeded up to 3 times per year
[3] Can be exceeded up to 18 times per year
[4] Can be exceeded up to 35 times per year
[5] From the 2008 Turkish air quality regulations

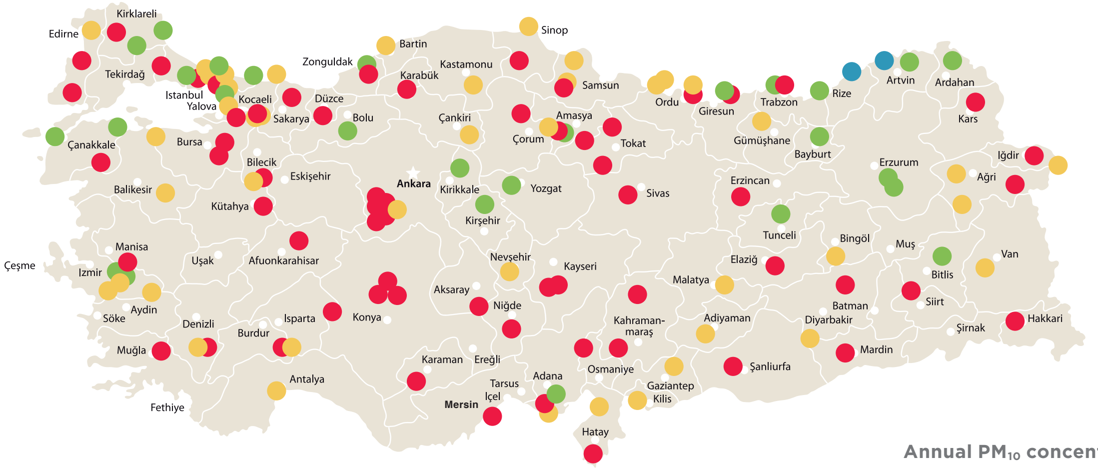
Moreover, the Turkish Air Quality regulations allow some time lag before the new standards come into effect. Since 2014 the Turkish standards are gradually being tightened until they match those of the EU. The lag time varies with parameter and exposure time, as indicated in Table 1. For CO, the final air quality standards came into effect in 2017, compared with 2019 for 24-hour PM_{10} and hourly SO_2; and 2024 for hourly NO_2.

1.3 Pollutants of concern and most vulnerable regions

The last available air quality data (2017) were compiled from the national air quality monitoring stations maintained by the Ministry of Environment and Urbanization.[4] As noted above, the Turkish air quality standards are being improved annually until they are in line with EU standards.

The analysis reveals that the highest SO_2 concentrations in 2017 were observed at the Edirne – Keşan, Amasya – Suluova, and Çorum – Mimar Sinan stations. The highest NO_2 concentrations were observed at the Ordu – Ünye, Samsun – Yüzüncüyıl, and Kayseri – Hürriyet stations. Hourly CO concentrations can be high at some locations, whereas annual CO concentrations are significantly lower than the air quality standard of 10,000 µg/m³.

Annual PM10 concentration, averaged over all available air quality stations, is 54 µg/m³. This exceeds the annual PM_{10} air quality standard of 40 µg/m³. Thus, PM_{10} is the air pollutant of greatest concern in Turkey. The highest PM_{10} concentrations are observed at Iğdır, Kahramanmaraş – Elbistan, and Ankara – Kayaş. Figure shows annual PM_{10} concentrations throughout Turkey. Maps for other pollutants and exposure periods are provided in Annex 2 of this report.



Annual PM_{10} standard: 40 µg/m³

Annual PM_{10} concentrations (µg/m³)

- >60
- 40–60
- 20–40
- 0–20
- Cities

Figure 2: Measured annual PM_{10} concentrations (average 2017)

Source: own

[4] Available at http://www.havaizleme.gov.tr/Services/AirQuality. 2017 data selection based on latest release from the Ministry.

1.4 Health effects of air pollution

Air pollution is a major environmental health risk. It is responsible for 7 million premature deaths globally; an estimated 4.2 million premature deaths are attributed to ambient (outdoor) and 2.8 million to household (indoor) air pollution (EEA, 2019). The pollutants of greatest concern for public health include PM, SO_2, NO_2, and ozone (O_3). The health risks are especially high for particulate matter smaller than 10 and 2.5 microns in diameter (PM_{10} and $PM_{2.5}$, respectively). In 2013, particulate matter was classified as a cause of lung cancer by the WHO's International Agency for Research on Cancer (IARC) as it is capable of penetrating deep into lung passageways and entering the bloodstream, causing cardiovascular, cerebrovascular, and respiratory impacts.

According to the WHO (2020), both short- and long-term exposure to ambient air pollution can lead to:

- Brain: Increased cerebrovascular ischemia, dementia.
- Blood: Altered rheology, increased coagulability, translocated particles, peripheral thrombosis, reduced oxygen saturation.
- Cells: Bladder cancer, skin cancer, obesity, diabetes.
- Lungs: Inflammation, oxidative stress, accelerated progression and exacerbation of chronic obstructive pulmonary disease (COPD), increased respiratory symptoms, effected pulmonary reflexes, reduced lung function, higher lung cancer risk.
- Heart: Altered cardiac autonomic function, oxidative stress, increased dysrhythmic susceptibility, altered cardiac repolarisation, increased myocardial ischemia.
- Children: Pre-eclampsia of the pregnant mother, pre-term birth, reduced birth weight, pollutants can reach the placenta, increased asthma risk and increased frequency of attacks for already asthmatic children, ADHD.
- Vasculature: Atherosclerosis, accelerated progression and destabilisation of plaques, endothelial dys-function, vasoconstriction, and hypertension.

For Turkey, the WHO attributed an estimated 36,698 deaths to ambient air pollution annually (WHO, 2018). These deaths are mainly caused by:

- Ischemic heart disease: 47.2% (17,331 deaths).
- Chronic obstructive pulmonary disease: 19.5% (7,153 deaths).
- Stroke: 13.7% (5,020 deaths).
- Trachea, bronchus, lung cancers: 13.2% (4,867 deaths).
- Lower respiratory infections: 6.3% (2,327 deaths).

The Health and Environmental Alliance (HEAL) further estimates that air pollution from coal-fired power plants in Turkey accounted for 2,876 premature deaths in 2015. A recent study reveals that 51,574 preventable deaths in Turkey are attributed to $PM_{2.5}$ pollution annually (Temiz Hava Hakkı Platformu, 2019).

2. A five-step approach to quantifying health costs

The methodology for quantifying the health effects of emissions from electricity generation in Turkey was based on a five-step process, comprising:

1. Identifying power generation from coal- and natural gas-fired power plants for the base year 2017.

2. Building various scenarios for the power sector from 2017 to 2028.

3. Calculating emission rates for the different electricity generation scenarios.

4. Modelling the dispersion of various air pollutants (primary and secondary).

5. Calculating the health impacts and associated costs for the different scenarios.

2.1 Identifying fossil fuel power plants in Turkey

As Turkey does not report its emissions from thermal power plants, neither individually such as The European Pollutant Release and Transfer Register (E-PRTR) nor cumulatively, the atmospheric emissions from individual power plants were estimated for the base year 2017 based on the capacity and fuel type data registered by the Energy Market Regulatory Authority (EMRA, EPDK in Turkish). Based on these data, there are currently 42 coal-fired and 37 natural gas-fired power plants in Turkey that have installed capacities higher than 100 MW. Electricity generated in 2017 from coal and natural gas power plants was 97.5 TWh and 97.2 TWh electricity, respectively.

2.2 Calculating emissions rates

Air pollutant emission rates are needed to model the impacts of the base year electricity generation and future electricity generation scenarios on air quality. The emission rates consist of the atmospheric emissions of the different pollutants (in grams) for each gigajoule (GJ) of energy generated. The emission rates were estimated based on the amount of electricity produced, the type of fuel used, and the emission factors given in Table 2. A wide range of emission factors are reported in the literature, depending on the type of fuel used and power plant technology. The values presented in Table 2 are recommended values taken from the 2016 EMEP/EEA Air Pollutant Emission Inventory Guidebook (EEA, 2019). Table 2 also includes the emission factors for mercury (Hg), which were used to estimate annual mercury emissions from fossil fuel power plants and their associated health costs.

Table 2: Emission factors for different fuel types

Source: own

Fuel Type	Emission Factors (g/GJ)				
	SO_x	CO	NO_x	PM_{10}	Hg
Natural Gas	0.281	39	89	0.89	0.0001
Hard Coal	820	8.7	209	7.7	0.0014
Lignite Coal	1680	8.7	247	7.9	0.0029

Data source: EMEP/EEA Air Pollutant Emission Inventory Guidebook 2016:
Chapter 1.A.1.a — Public Electricity and Heat Production: *Table 3-2/3/4: Tier 1 emission factors for source category 1.A.1.a using hard coal/ brown coal/gaseous fuels*

2.3 Power generation scenarios

The co-benefits assessment for Turkey takes a policy-directed scenario approach, to connect with existing policy environments and learn from comparing the socioeconomic performance of various potential energy transition pathways in Turkey. The reference policy pathways, as the scenarios are called in this context, have been developed and selected in consultation with government and expert organisations, to allow for:

- Connectivity and comparability with Turkey's official climate and energy policies, strategies, or roadmaps (existing or considered), to ensure the political relevance and usability of the assessment results.
- Suitability as calculation basis for scientifically sound, quantitative assessments of socio-economic impacts.

Against this background, four scenarios were defined to assess the potential benefits of increasing the share of renewable energy in Turkey's future electricity generation mix in the year 2028 (see Table 3 and Figure 3 below): Building on the base year (2017) for this study, the four scenarios project an increase of total generation by one-third, from around 300 TWh (2017) to around 400 TWh (2028).

1. **Base year (2017):** For the base year of the study the Turkish Electricity Transmission Corporation (TEİAŞ) reported 30.3 GW renewable energy installed capacity with a total generation of 68.0 TWh, accounting for 23% of total power generation[5].

2. **Current Policy Scenario:** Based on projections by the Turkish Electricity Transmission Corporation (TEİAŞ) for 2026, proportionally adjusted for 2028. Under this scenario, in 2028 renewable energy installed capacity amounts to 61.5 GW, with a total generation of 142.0 TWh, accounting for 36% of total power generation.

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[5] The energy sources used to calculate the generation shares in this report cover 99% of the power generated in the base year 2017. When including the remaining energy sources such as diesel or biomass, the rounded percentage of renewable energy sources (23% for 2017) would remain unchanged. Hence, no major discrepancies are expected for the 2028 target year.

The four scenarios have been defined for the COBENEFITS assessment studies in Turkey, based on the methodological approach developed in the SHURA Energy Transition Center report on Turkey's future renewable energy shares in electricity generation[6]. For each scenario, the generation rates were provided for a 5 km × 5 km grid, which created the geographical template for the air pollution analysis. Electricity generation data for the 2017 base year and the 2028 scenarios is provided in Table 2 .

Table 3: Electricity generation projections (TWh) under different scenarios

Source: own

Type of Fuel	Base Year 2017	2028 Current Policy Scenario	2028 New Policy Scenario	2028 Advanced Renewables A	2028 Advanced Renewables B
Hard Coal	55.9	53.5	47.5	43.6	34.0
Lignite	41.6	43.1	37.5	35.1	30.5
Natural Gas	97.2	138.3	125.5	118.3	100.1
Nuclear	0	16.1	15.3	14.5	11.9
Solar PV	2.9	10.8	27.8	36.4	52.5
Wind	17.9	38.9	47.3	53.2	72.9
Hydro	58.2	90.8	90.8	90.8	90.8

Base year 2017 data are based on TEİAŞ reports (coal, gas) and on IEA Data (for solar PV, wind, and hydro). 2028 Projections defined for the COBENEFITS assessment studies in Turkey, based on the methodological approach developed in the SHURA Energy Transition Center.

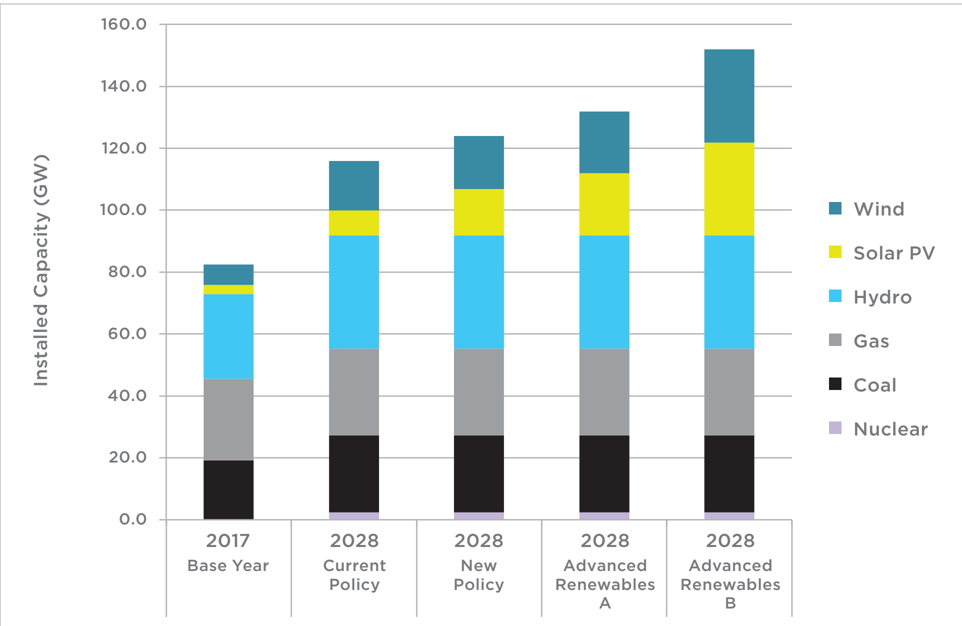

Figure 3: Electricity generation capacity projections under different scenarios

Source: own

[6] Increasing the Share of Renewables in Turkey's Power System: Options for Transmission Expansion and Flexibility, SHURA Energy Transition Center, 2018.

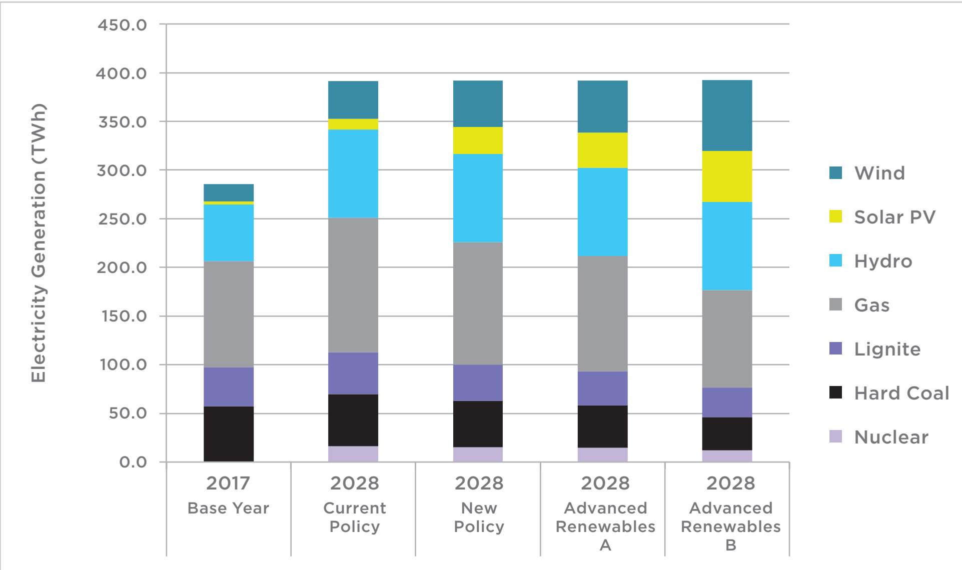

Figure 4: Electricity generation scenarios for different fuel types (TWh)
Source: own

2.4 Modelling the dispersion of pollutants

Dispersion modelling was used to assess how the electricity production scenarios, defined in Section 2.3, affect air quality. The modelling was conducted using the CALPUFF modelling system, which is recommended by the U.S. Environmental Protection Agency for assessing long-range transport of pollutants. The model domain was defined to encompass the whole of Turkey. The goal was to identify, at the national level, air quality hotspots resulting from electricity generation, and to quantify the potential benefits of increasing renewables in Turkey's electricity generation mix.

The CALPUFF modelling system consists of three programs: CALMET, a three-dimensional meteorological model; CALPUFF, the main atmospheric pollution dispersion model; and CALPOST, a post-processing model for the evaluation and visualisation of results. The analysis was conducted for the pollutants CO, SO_2, NO_2, and PM_{10}.[7]

The CALPUFF model is a non-steady-state pollutant transport model that can simulate the dispersion of gases as well as particulate matter for spatially variable meteorological data. CALPUFF has undergone extensive development to include the latest concepts for modelling pollutant dispersion and air quality. CALPUFF has been used in numerous studies to simulate air pollutant concentrations and the health impacts of various anthropogenic sources of pollution. In the present study, the model was used to simulate the contribution of existing electricity generation (as for 2017) to air pollution in Turkey, and subsequently to assess the impacts of the different renewable scenarios on air quality.

An important requirement for conducting air dispersion modelling is to define the geophysical and meteorological conditions over the domain of interest. To represent these conditions, the following data were incorporated into the CALMET model:

- Hourly surface meteorological data (for the year 2017) for 20 meteorological stations located throughout Turkey.
- Twice-daily upper-level data (for the year 2017) from 5 upper-level stations located in different regions of Turkey.
- Detailed topographical and land use data.

[7] The analysis was based on CALPUFF/CALMET version 5.8.5 which is the USEPA version obtained from the official CALPUFF webpage: http://www.src.com

The data were used in CALMET to define the three-dimensional hourly wind field and meteorological data over the entire model domain. These parameters control the movement and spread of air pollutants.

The CALPUFF program simulated the impacts of electricity generation on air quality, based on: (i) the wind field meteorological data generated by CALMET; (ii) 2017 base year electricity generation data used for the 2028 electricity generation scenarios (Section 2.3); and (iii) the emission factors defined in Section 2.2. The analyses were conducted for the four pollutants on an hourly basis for an entire year, to account for different weather/meteorological conditions.

The model domain covers all of Turkey (1800 km by 800 km) and all fossil-fuel power plants simultaneously. The pollutant impacts were calculated at geographical locations corresponding to a uniform grid of receptors spread over the entire model domain (total of 3600 ground-level receptors at 20 km spacing). This grid was deemed sufficient to evaluate the spatial distribution of air pollutants at the national level and to provide a tool for comparing predicted health effects associated with the various electricity generation scenarios.

It is assumed in the model that all emitted SO_x is in the form of SO_2, and that emitted NO_x is 10% NO_2 and 90% NO (Mangia, 2015). Besides PM_{10} directly emitted from the power plants, the model accounted for the chemical formation of secondary particle matter in the atmosphere. Specifically, CALPUFF's reaction module accounted for the formation of secondary ammonium sulphate and ammonium nitrate resulting from the SO_2 and NO_x emissions from power plants in combination with background concentrations of ammonia and ozone. As ammonia is not regularly monitored in Turkey, the recommended default value of 10 ppb was used in the calculation. Background ozone concentration was set at 50 ppb, corresponding to the average ozone concentration observed at Turkish monitoring stations in 2017. The formed secondary particulate matter is typically within range, that is, in the $PM_{2.5}$ category.

2.5 Scope of the study

To model the dispersion of atmospheric pollutants, emission data are required from individual power plants. However, this information is not available publicly in Turkey. To circumvent the lack of data, electricity generation data from the Seffaflık Platformu (Energy Exchange Istanbul- EXIST) were used instead. EXIST is an energy exchange company legally incorporated under the Turkish Electricity Market Law and enforced by the Energy Markets Regulator Authority (EMRA). Therefore, pollutant emissions for the 2017 base year were calculated using electricity generation data from the Seffaflık Platformu combined with EMEP/EEA emission factors (Table 2).

Despite the existence of a wide range of methods to calculate health effects and their associated costs applicable to Europe, there is a lack of studies applicable to Turkey. In the current study, we applied exposure–response coefficients from the Economic Valuation of Air Pollution (EVA) model to estimate the health effects of pollutant emissions (Brandt et al., 2013).

Specific health-related costs are also unavailable in Turkey. Therefore, to estimate the health-related external costs due to atmospheric emissions from thermal power plants, the EVA model system was used. However, the EVA valuation is based on the 2006 PPP (purchasing power parities) of Denmark. To adjust these costs to the current Turkish context, the costs estimated with the EVA methodology were scaled by the ratio of Turkey's PPP to Denmark's PPP (according to the OECD,[i] this ratio for 2017 was 1.45/7.49=0.191).

3. Declining health costs and reducing negative impacts on health

Hotspots and maximum pollutant concentrations in Turkey were calculated using with the CALPUFF dispersion model. The analysis revealed that maximum annual SO_2 concentrations are particularly high, in some instances more than 10 times higher than the air quality standards. The levels of fine secondary PM are also high and likely to cause significant adverse effects. NO_2 and primary PM_{10} levels are moderately high. On the other hand, CO concentrations are significantly lower than the maximum permissible levels.

The health effects and mortality associated with the different scenarios were calculated from population statistics and the outputs of the dispersion model, as follows:

Number of cases $_a$ = [pollutant concentration $_a$] × [affected population $_a$] × [exposure–response coefficient]

Table 4: Total mortality due to air pollution under different scenarios

Source: own

		2017 Base Year	2028 Current Policy	2028 New Policy	2028 Advanced Renewables A	2028 Advanced Renewables B
Total Mortality	cases	2,103	2,333	2,042	1,892	1,564

Here, **a** denotes the year (2017 or 2028) for which the analysis is conducted.

Pollutant concentration: This is the average annual pollutant concentration for each province as predicted by the air pollution dispersion model for the different scenarios. The model considered SO_2, NO_2, CO, and PM. PM includes primary $PM_{2.5}$ (assumed to be 67% of emitted PM_{10} as suggested by the WHO), as well as secondary PM produced in the atmosphere from NO_3 (−) and SO_4(−2) emissions (ammonium nitrate and ammonium sulphate).

Affected population: This refers to the population exposed to the pollutant concentration. The population groups considered, as defined in the EVA methodology, are: adult population (≥15 years old), and infant population (population 0–14 years old).

Province-level populations and age distributions were obtained from the TurkStat website for the base year (2017). TurkStat population projections were only available up to 2025, so the data was extrapolated to estimate population and age distributions in 2028.

Exposure–response coefficient: This study used exposure–response coefficients given in the EVA system tested for Denmark, Europe, and the USA, as Turkey-specific exposure–response coefficients are not available. The EVA system was selected over other methodologies as it is a reasonable approximation, based on a recent cohort study of 500,000 individuals (initially for the year 2000, with updates in 2004 and 2005), and is supported by the WHO and applicable to European conditions.

Table 4 presents the health effects due to atmospheric emissions for the baseline scenario and the alternative electricity generation scenarios.

The predicted years of life lost (YOLL) was translated into mortality, assuming that life expectancy in Turkey is 78 years based on data provided by TurkStat (Figure 3 and Table 5).

Table 5: Health impacts due to air pollution under different scenarios

Source: own

			2017 Base Year	2028 Current Policy	2028 New Policy	2028 Advanced Renewables A	2028 Advanced Renewables B
Morbidity	Chronic Bronchitis (PM)	cases	5,787	7,093	6,306	5,881	4,931
	Restricted Activity Days (PM)	days	48,953	59,364	52,778	49,216	41,270
	Congestive Heart Failure (PM)	cases	2,853	3,436	3,054	2,848	2,388
	Congestive Heart Failure (CO)	cases	6	9	8	8	7
	Lung Cancer (PM)	cases	1,163	1,401	1,245	1,161	974
Hospital Admissions	Respiratory (PM)	cases	319	385	342	319	267
	Respiratory (SO_2)	cases	359	371	322	297	243
	Cerebrovascular (PM)	cases	777	936	832	776	651
Asthma, Children <14 yr	Bronchodilator use (PM)	cases	2,804,479	3,184,093	2,830,842	2,639,790	2,213,594
	Cough (PM)	days	9,696,104	11,008,571	9,787,254	9,126,715	7,653,200
	Lower respiratory symptoms (PM)	days	3,739,305	4,245,458	3,774,457	3,519,720	2,951,458
Asthma, Adults >15 yr	Bronchodilator use (PM)	cases	19,196,317	23,528,357	20,918,065	19,506,311	16,357,003
	Cough (PM)	days	19,760,914	24,220,368	21,533,302	20,080,026	16,838,091
	Lower respiratory symptoms (PM)	days	7,128,044	8,736,633	7,767,370	7,243,152	6,073,740
Mortality	Acute Mortality (SO_2)	cases	1,383	1,428	1,237	1,141	935
	Chronic Mortality YOLL (PM)	YOLL	55,332	69,755	62,016	57,830	48,494
	Infant Mortality (PM)	cases	10	11	10	9	8

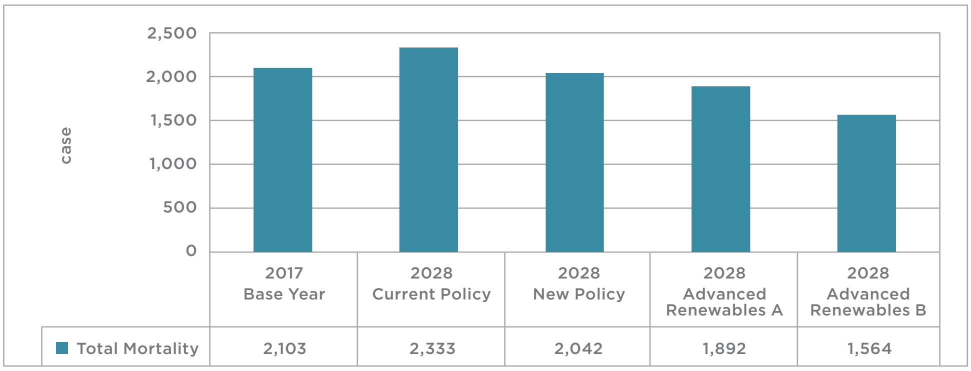

Figure 5: Total mortality for the base year and for future energy generation scenarios

Source: own

The results suggest that atmospheric emissions from fossil-fuel power plants were responsible in 2017 for 2,103 deaths in Turkey. With the Current Policy scenario, this number is estimated to increase in 2028 to 2,333 mortalities. Under the New Policy and Renewables scenarios (Scenarios 2, 3 and 4), annual mortalities in 2028 are estimated to decline to 2,042, 1,892 and 1,564 cases, respectively.

In addition to the costs associated with SO_2, CO, and PM, the health-related costs of Hg emissions were also calculated. Hg emission factors are given in Figure 6. The Hg damage cost factor used in the calculations is USD 1,500 per kg (Im, 2018).

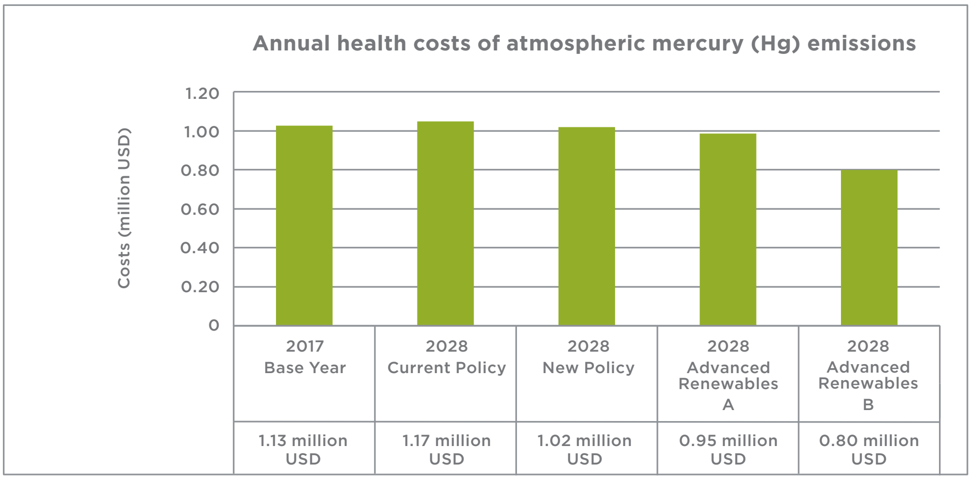

Figure 6: Health costs of atmospheric mercury (Hg) emissions from fossil fuel power plants (Turkey)

Source: own

An increased share of renewable energy in Turkey's electricity generation mix can provide significant health-related savings. The annual health-related costs of pollutants emitted from fossil-fuel power plants are estimated as USD 2.15 billion in 2017. Under the Current Policy scenario, this is predicted to increase by more than 380 million to USD 2.54 billion in 2028. Conversely, the annual costs corresponding to the New Policy and Advanced Renewables scenario A and B will reduce 2028 health-related costs to USD 2.24 billion, 2.08 billion and 1.74 billion, respectively.

		2017 Base Year	2028 Current Policy	2028 New Policy	2028 Advanced Renewables A	2028 Advanced Renewables B
Health Costs (million USD)	Total Mortality Cost	1,549	1,809	1,594	1,481	1,231
	Total Morbidity Cost	82.44	100.71	89.53	83.49	70.02
	Total Hospital Admissions Cost	2.83	3.30	2.92	2.72	2.27
	Total Asthma Cost	518.53	622.06	553.04	515.72	432.45
	Hg Damage Cost	1.13	1.17	1.02	0.95	0.80
	Total Health Cost	2,154.27	2,536.45	2,240.47	2,083.55	1,736.94
	Cost Relative to Base Year		382.18	86.20	−70.72	−417.33

Table 6: Annual health-related costs due to air pollution under different scenarios (million USD)

Source: own

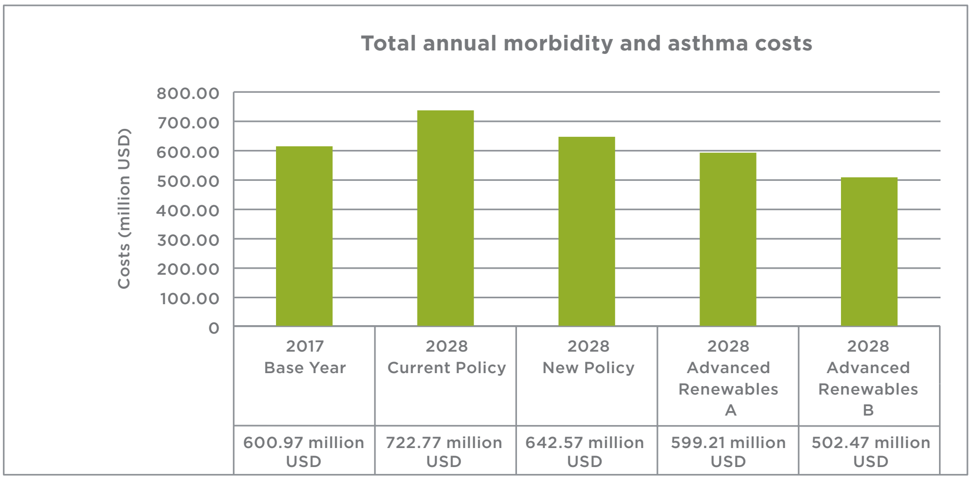

Figure 7: Total morbidity and asthma costs (million USD)

Source: own

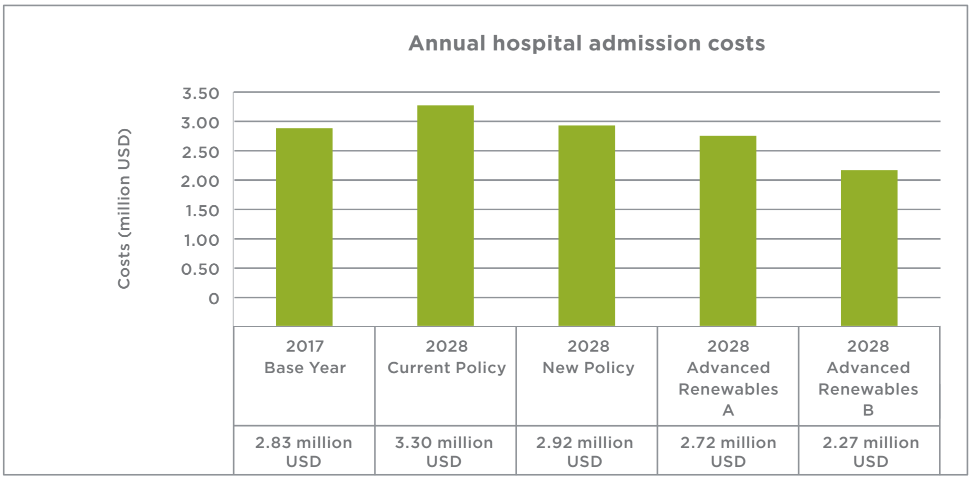

Figure 8: Total hospital admission costs (million USD)

Source: own

4. Creating an enabling environment to improve people's health and unburdening health systems

Impulses for furthering the debate

This COBENEFITS study assesses the impacts of fossil-fuel power plants in Turkey on people's health. It quantifies the benefits of unburdening Turkey's health system, in terms of health cost savings and reduction in premature deaths, which can be achieved by decarbonising Turkey's power sector through renewable energy.

The analysis shows that Turkey can significantly reduce the number of premature deaths related to air pollution from fossil fuel power plants, by increasing the share of renewables in its power mix. With the Current Policy pathway, mortality can be expected to increase from 2,103 in 2017 to 2,333 in 2028. Under the Advanced Renewables B scenario, mortalities could be decreased to 1,564 cases in 2028, thus saving more than 750 lives annually. In addition, Turkey can make significant health cost savings by decarbonising the power sector. Under the current policy, annual health-related costs can be expected to increase from USD 2.15 billion in 2017 to USD 2.54 billion in 2028. By following the ambitious decarbonisation pathway for Turkey's power sector (Advanced Renewables B), health costs could be lowered to USD 1.74 billion in 2028, representing savings USD 800 million annually.

Harnessing these potential gains from an increased share of renewables in electricity production requires creation of an enabling environment for the overall electricity sector, in order to facilitate the transition to renewables-based generation. The enabling environment and enablers of the desired change can be assessed along various societal dimensions, including visionary, cultural, policy/regulatory, organisational, and economic aspects, which comprise multiple social actors and their interactions (Yazar et al, forthcoming). In the following section three principal directions of policy-related, regulatory, and organisational enablers are being suggested, as impulse for furthering this important debate.

Policy-Related:

Eliminate existing subsidies for coal-fired power plants

Under the existing coal subsidies, national energy economics play against clean renewable energy, thereby additionally burdening Turkey's health systems. In order to create a level playing field between renewables and fossil-fuelled power plants, coal subsidies will have to be eliminated. Prior studies reveal that, among the G20 countries, Turkey is one of the heaviest subsidisers of coal (EEA, 2019a). These subsidies are implemented thorough various instruments that pervade the entire lifecycle of coal, from imports and extraction to its use in industrial processes and through direct household consumption. These subsidies — in the form of direct transfers, price controls, purchase guarantees, tax exemptions, capacity guarantees, and various other instruments — effectively reduce the investment, operation, and maintenance costs of coal power plants, thereby making them appear artificially attractive compared with renewable alternatives (Şahin, 2015).

Regulatory:

Follow the international environmental agenda

Turkey can actively participate in the Gothenburg Protocol, and report emissions from individual power plants to international bodies such as the European Pollutant Release and Transfer Register (E-PRTR). Ratification of the Paris Agreement on climate change, and progressive improvements in national greenhouse emissions targets, will indirectly serve the goals of improving air quality and also reducing health costs resulting from air pollution.

Organisational:

Ensure data availability and transparency

There is currently a lack of data specific to the Turkish context, concerning the health impacts associated with burning fossil fuels. Relevant governmental bodies and research funding institutions can facilitate research on these issues in order to generate nationwide data on exposure–response relationships, mortality and morbidity statistics, and health costs. Furthermore, the Ministry of Energy can ensure public access to air pollutant emission data from individual power plants — detailing fuel, technological, and emission control standards. This would improve public awareness of air pollution and its health impacts; empower citizens to pursue change; assist monitoring and analysis by researchers and other non-governmental bodies; and encourage compliance with environmental protection standards.

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Abbreviations

CLRTAP	Convention on Long-Range Transboundary Air Pollution
CO	Carbon monoxide
EEA	European Environment Agency
E-PRTR	European Pollutant Release and Transfer Register
EU	European Union
EVA	Economic valuation of air pollution
GJ	Gigajoule
HEAL	Health And Environmental Alliance
Hg	Mercury
IARC	International Agency for Research on Cancer
IASS	Institute for Advanced Sustainability Studies, Potsdam
IEA	International Energy Agency
IPC	Istanbul Policy Center, Sabanci University
NO_2	Nitrogen dioxide
NO_x	Nitrogen oxides
O3	Ozone
PM_{10}	Particulate matter smaller than 10 µm
$PM_{2.5}$	Particulate matter smaller than 2.5 µm
PPP	Purchasing power parity
PV	Photovoltaic
SO_2	Sulphur dioxide
SO_x	Sulphur oxides
TEİAŞ	Turkish Electricity Transmission Corporation
WHO	World Health Organization
YOLL	Years of life lost

Annexes

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Annex 1: Spatial distribution of operational electricity-generating power plants

The Energy Market Regulatory Authority (EMRA) is responsible for licensing the operations of all electricity plants in Turkey. Approved licenses are announced online on the official website: http://lisans.epdk.org.tr/epvys-web/faces/pages/lisans/elektrikUretim/elektrikUretimOzetSorgula.xhtm.

Based on these datasets, all coal-fuelled power plants and natural gas plants of more than 100 MW installed capacity were compiled and shown in Figure A1 and Figure A2 .

Coal Power Plants: By the end of 2017, there were 42 operating coal-fired power plants in Turkey and new plants have since been added. These power plants use lignite, hard coal, or asphaltite, and generated 97.5 TWh electricity in 2017. Information on installed capacities, fuel type, and geographical coordinates were extracted from the EMRA list. For some plants, coordinates were missing on the EMRA website, therefore information from the operator and Google Maps was used to determine their locations.

Natural Gas Plants: By the end of 2017, there were 37 operating natural gas plants with an installed capacity greater than 100 MW. These plants generated 97.2 TWh electricity in 2017. New plants have since been added.

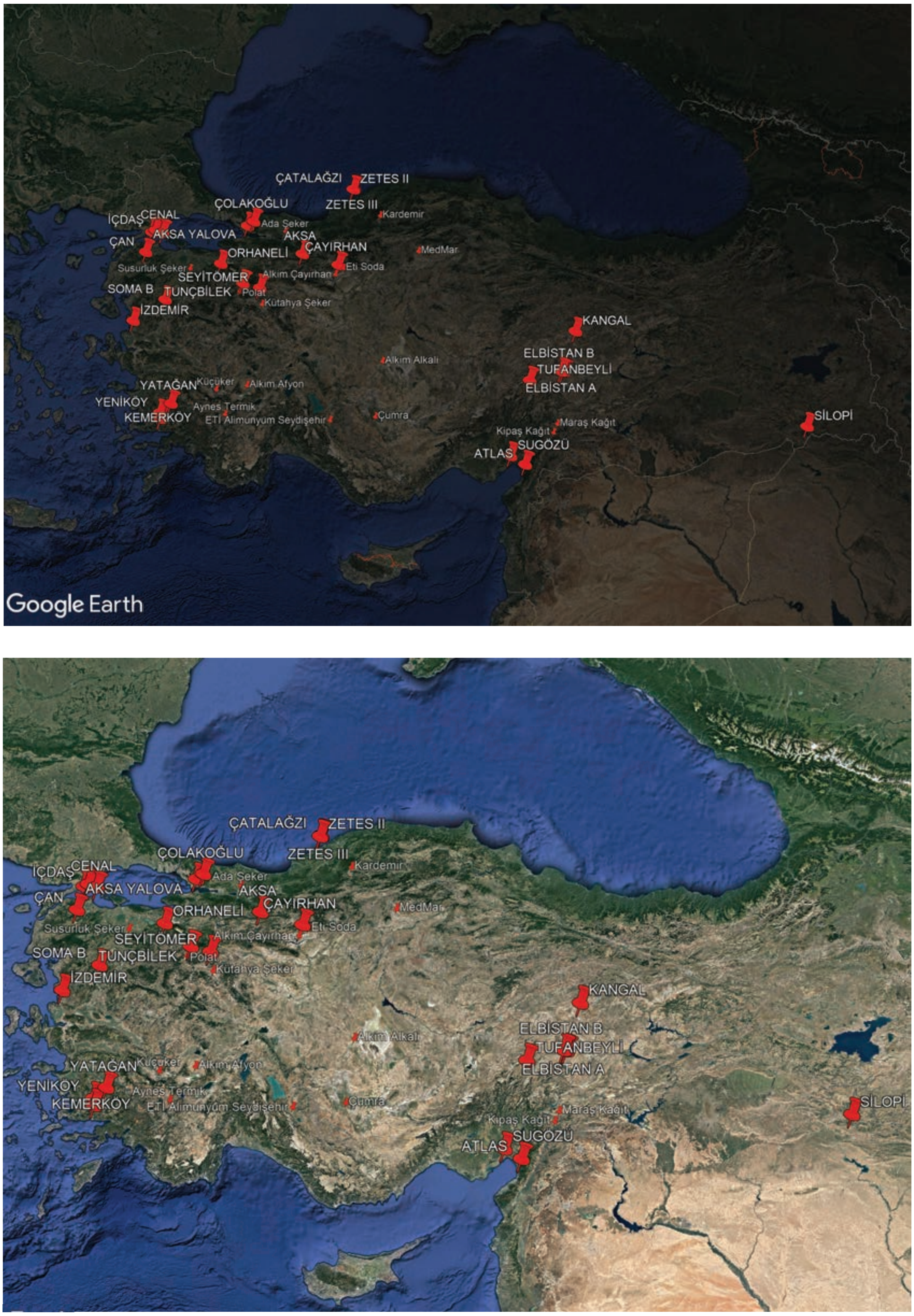

Figure A1: Installed coal-fuelled (hard coal, lignite, asphaltite) power plants

Source: own (data), Google (map)

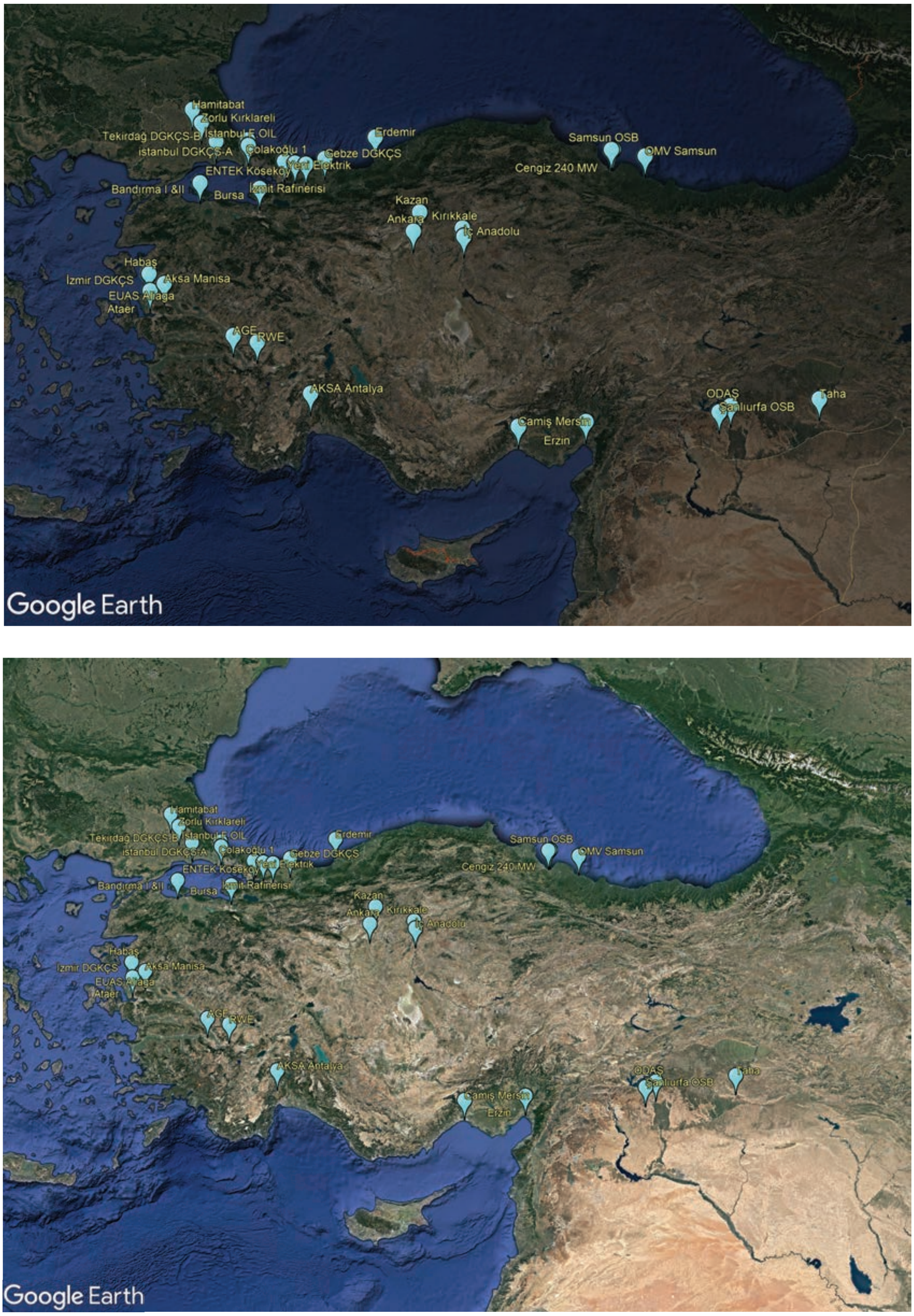

Figure A2: Installed natural gas-fuelled power plants

Source: own (data), Google (map)

Annex 2: Air pollution level 2017

The maps presented in Figure A3 – Figure A11 show air quality data for the four selected parameters (SO_2, NO_2, PM_{10} and CO) and for different exposure times. Each circle represents an air quality monitoring station. Only stations with at least 75% data coverage are included on the maps. Stations with more than 25% data omission are excluded because they do not allow for accurate determination of the number of exceedances. The compiled 2017 air quality data are compared with the 2017 Turkish air quality standards.

These maps reveal that the highest SO_2 concentrations are observed at the Edirne – Keşan, Amasya – Suluova, and Çorum – Mimar Sinan stations. The highest NO_2 concentrations are observed at the Ordu – Ünye, Samsun – Yüzüncüyıl, and Kayseri – Hürriyet stations. Annual PM_{10} concentration, averaged over all available air quality stations, is 54 µg/m³, which exceeds the annual PM_{10} air quality standard of 40 µg/m³, clearly revealing that the air pollutant of most concern in Turkey is PM_{10}. The highest PM_{10} concentrations are observed at Iğdır, Kahramanmaraş – Elbistan, and Ankara – Kayaş. Hourly CO concentrations are high at some locations, whereas the annual CO concentrations are significantly lower than the air quality standard of 10,000 µg/m³.

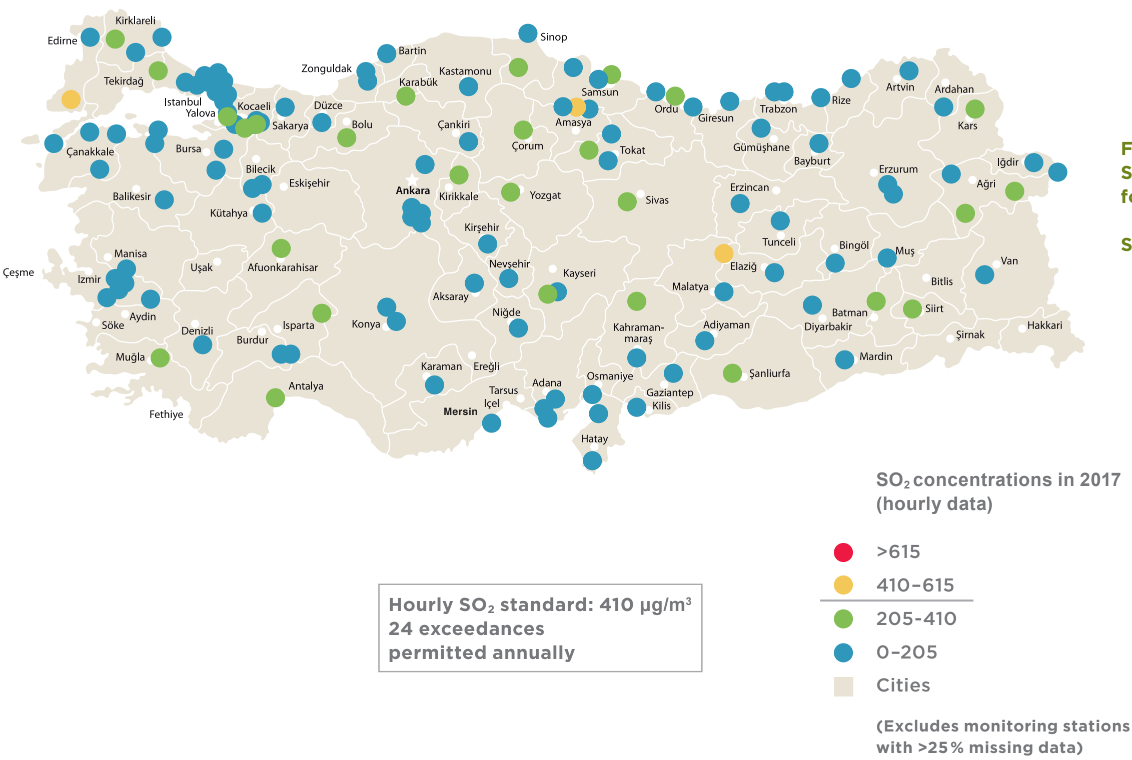

Figure A3: Hourly SO_2 concentrations for year 2017

Source: own

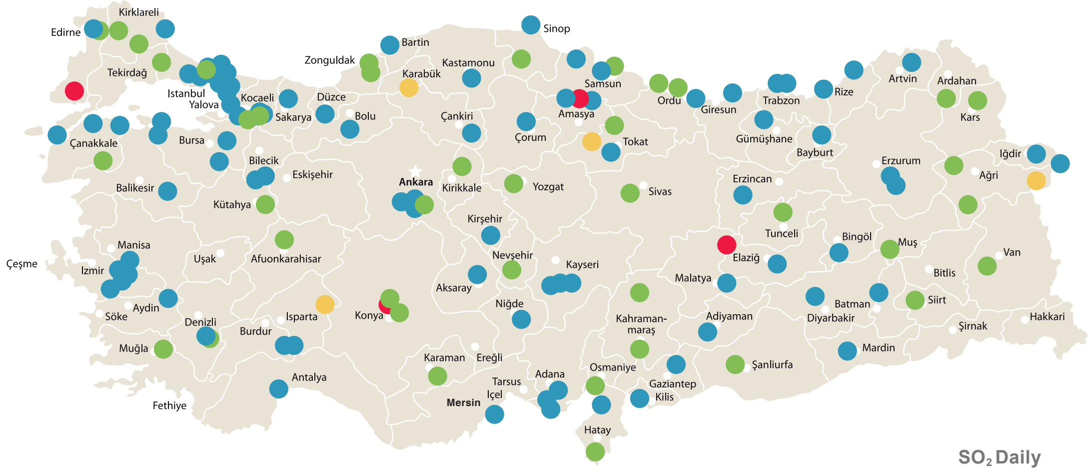

Figure A4: Daily SO_2 concentrations for year 2017

Source: own

SO_2 Daily

- 185 – more
- 125–185
- 60-125
- 0–60
- Cities

Daily SO_2 standard: 125 µg/m^3
3 exceedances permitted annually

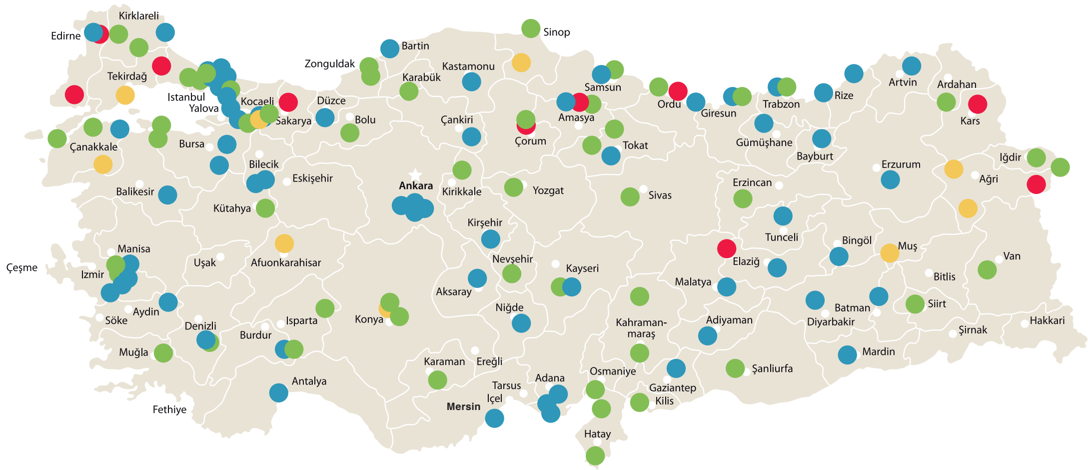

Figure A5: Annual SO_2 concentrations for year 2017

Source: own

Annual SO_2 standard: 20 µg/m^3

SO_2 Annual

- 30 – more
- 20–30
- 10 – 20
- 0–10
- Cities

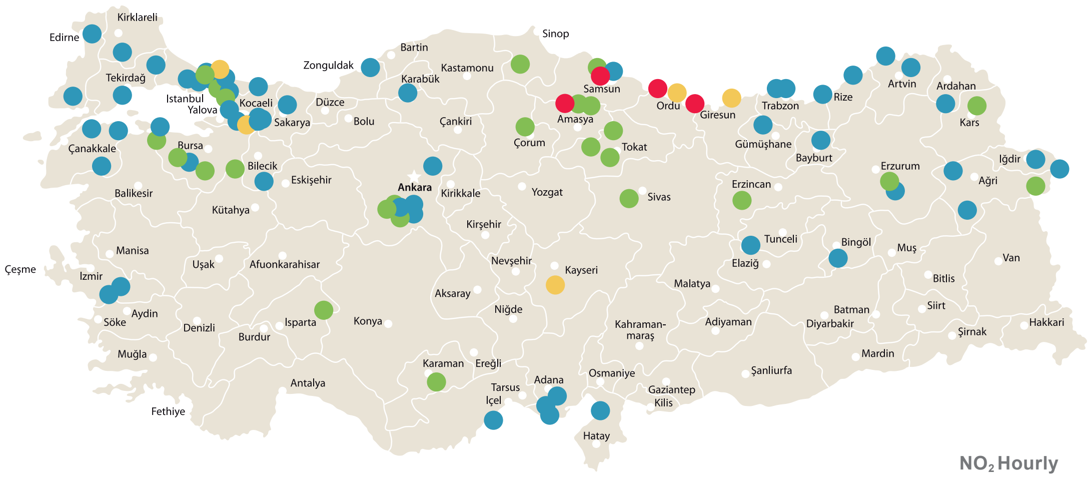

Figure A6: Hourly NO_2 concentrations for year 2017

Source: own

Hourly NO_2 standard: 270 µg/m3 18 exceedances permitted annually

NO_2 Hourly

- 405–more
- 270–405
- 135–270
- 0–135
- Cities

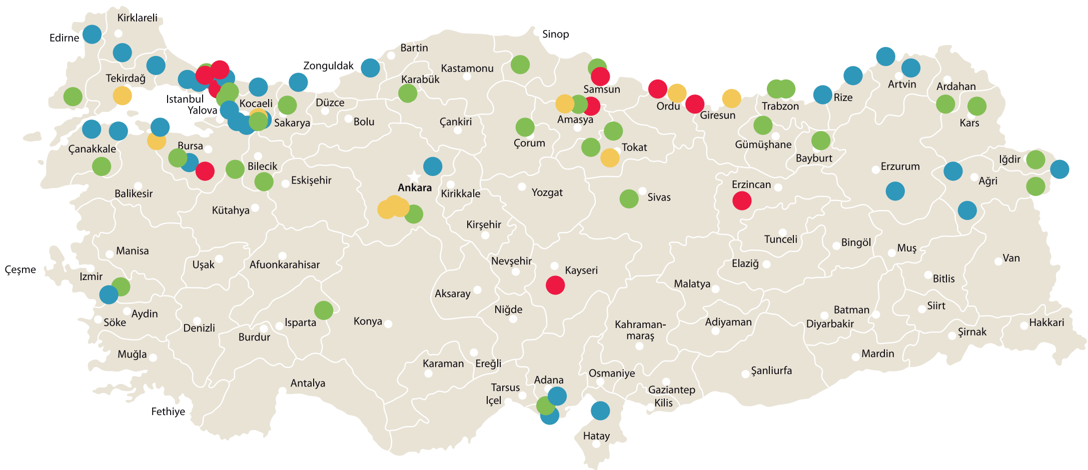

Figure A7: Annual NO_2 concentrations for year 2017

Source: own

Annual NO_2 standard: 40 µg/m³

NO_2 Annual

- 60–more
- 40–60
- 20–40
- 0–20
- Cities

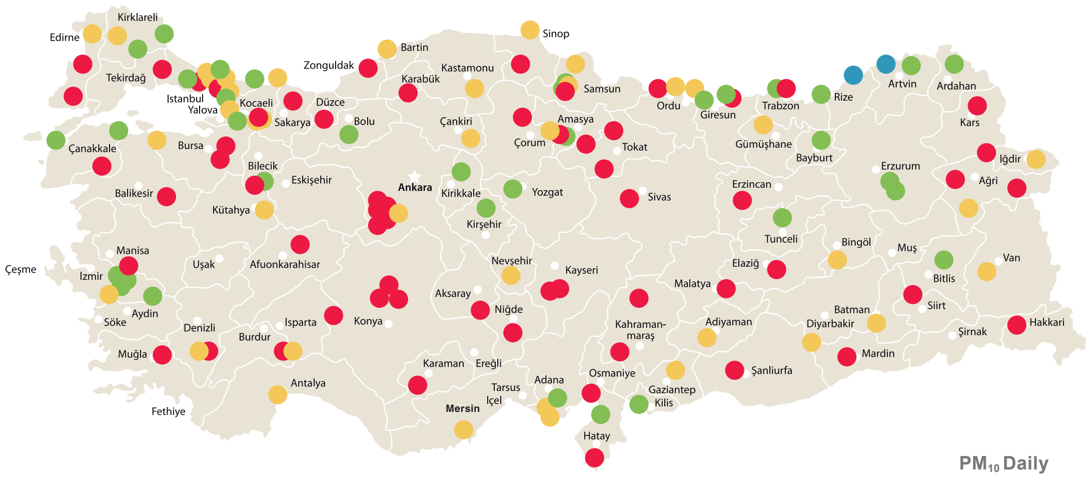

Figure A8: Daily PM_{10} concentrations for year 2017

Source: own

Daily PM_{10} Standard: 70 µg/m³
35 exceedances permitted annually

PM_{10} Daily

- 105–more
- 70–105
- 35-70
- 0–35
- Cities

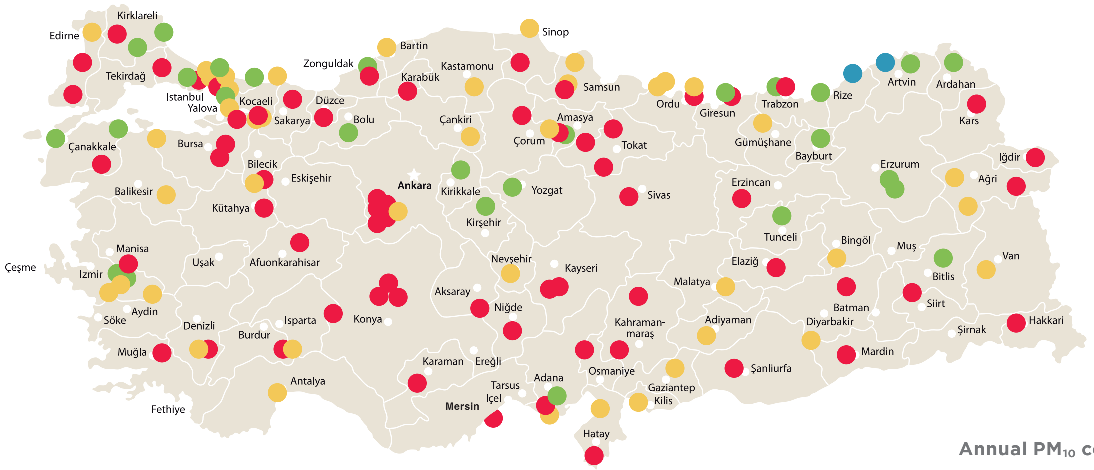

Figure A9: Annual PM_{10} concentrations for year 2017

Source: own

Annual PM_{10} concentrations (µg/m³)

- >60
- 40–60
- 20–40
- 0–20
- Cities

Annual PM_{10} standard: 40 µg/m³

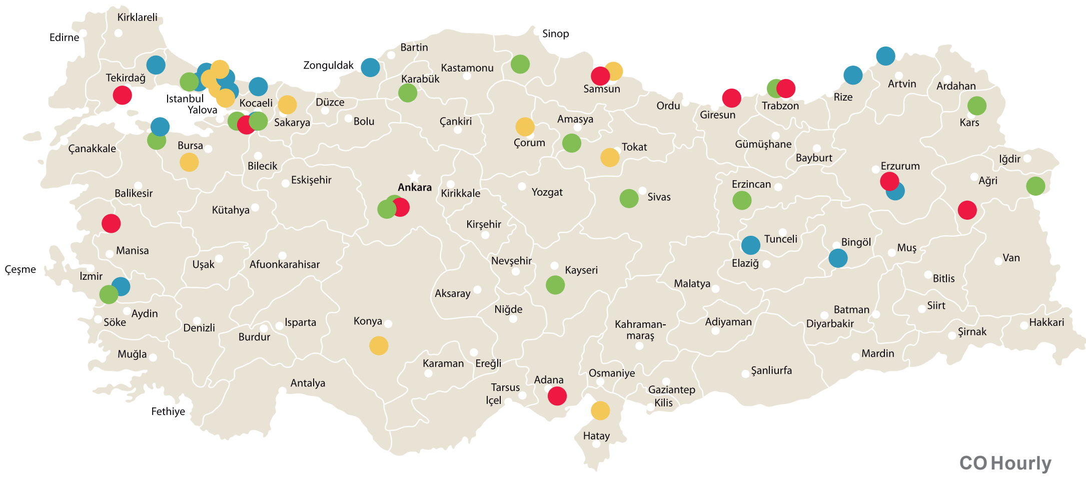

Figure A10: Hourly CO concentrations for year 2017

Source: own

Hourly CO standard: 10000 μg/m³

CO Hourly

- 15000 – more
- 10000–15000
- 5000–10000
- 0–5000
- Cities

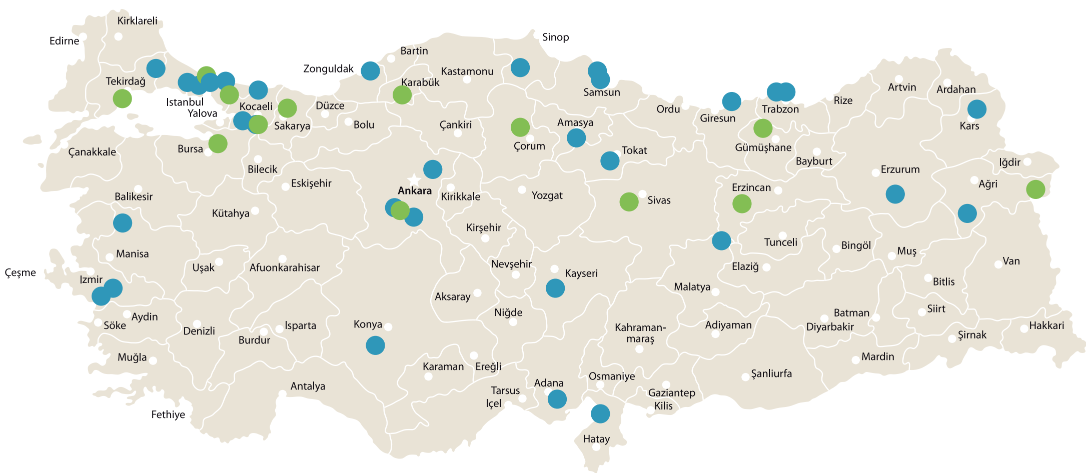

Figure A11: Annual CO concentrations for year 2017

Source: own

Annual CO standard: 10000 μg/m³

CO Annual

- 3000 – more
- 2000–3000
- 1000–2000
- 0–1000
- Cities

Annex 3: Hotspots of air pollution under various scenarios

A summary of hotspots and maximum pollutant concentrations predicted with the CALPUFF dispersion model is presented in Table A1 to Table A5. It is seen that predicted maximum annual SO_2 concentrations are particularly high, in some instances more than 10 times the air quality standards. The levels of fine secondary PM are relatively high and likely to cause significant adverse effects. NO_2 and primary PM_{10} levels are equally significant. CO concentrations, on the other hand, are much lower than the permissible levels.

Comparison of pollutant concentrations forecast for the different scenarios shows that the 2017 base year concentrations are lower in some instances than those predicted for the future scenarios. This is attributed to planned increases in installed power generation capacity between now and 2028. At other locations the future concentrations might be lower, depending on the generation rates under future scenarios. Moreover, the predicted air pollution concentrations consistently decrease with increases in renewable energy, clearly showing the potential for improved air quality by shifting to renewables. The overall benefit can be minor for some pollutants that are already at low concentrations (such as CO), whereas for other pollutants (particularly SO_2 and PM) a shift from the Current Policy to the Advanced Renewables Scenario can have achieve a large reduction in pollutant concentrations, by as much as 50% in some instances.

In summary, increasing the share of renewables in Turkey's electricity generation mix can have tangible and widespread co-benefits for air quality. The reliance on renewables for electricity generation can significantly reduce atmospheric concentrations of SO_2 and PM, and to a somewhat lesser extent NO_2. These improvements in ambient air quality translate to direct reductions in health impacts and associated costs.

Table A1: SO_2 hotspots and predicted maximum concentrations

Source: own

	Max Concentration of SO_2 (µg/m³)				
Location	**2017 Base Year**	**2028 Current Policy**	**2028 New Policy**	**2028 Advanced Renewables A**	**2028 Advanced Renewables B**
Silopi/Şırnak	17.1	—	—	—	—
Dursunbey/Balıkesir	16.0	—	—	—	—
Bodrum/Muğla	175.5	23.0	15.3	11.8	—
Çeşme/İzmir	19.6	—	—	—	—
Kınık/İzmir	103.8	38.0	25.6	20.4	11.1
Bayramiç/Çanakkale	145.6	99.2	65.5	49.9	32.5
Emet/Kütahya	54.5	291.2	266.8	250.1	197.6
Tepebaşı/Eskişehir	35.1	—	—	—	—
Beylikova/Eskişehir	48.7	25.7	17.4	13.2	—
Akçakoca/Düzce	154.6	116.5	100.2	90.6	69.0
Tufanbeyli/Adana	51.2	—	—	—	—
Afşin/Kahramanmaraş	71.7	343.4	313.6	297.0	253.9
Yumurtalık/Adana	220.4	49.0	41.6	36.9	25.9
Kangal/Sivas	27.0	—	—	—	—
Dazkırı/Afyon	—	150.8	149.7	148.0	143.0
Doğanhisar/Konya	—	247.7	244.9	242.5	233.0

	Max Concentration of NO_2 (μg/m³)				
Location	2017 Base Year	2028 Current Policy	2028 New Policy	2028 Advanced Renewables A	2028 Advanced Renewables B
Bodrum/Muğla	26.8	—	—	—	—
Çeşme/İzmir	13.1	11.7	10.2	9.5	7.6
Kınık/İzmir	17.1	6.3	—	—	—
Bayramiç/Çanakkale	23.9	15.2	13.8	12.6	9.6
Osmaneli/Bilecik	8.9	16.9	16.6	16.3	15.3
Beylikova/Eskişehir	7.6	—	—	—	—
Akçakoca/Düzce	41.3	30.5	26.5	24.1	18.8
Erbaa/Tokat	—	6.9	5.6	—	—
Bala/Ankara	5.9	8.2	8.0	7.9	7.2
Polatlı/Ankara	—	7.0	6.9	6.8	6.4
Yumurtalık/Adana	45.7	21.8	19.9	18.7	15.9
Tufanbeyli/Adana	7.9	—	—	—	—
Afşin/Kahramanmaraş	11.1	78.2	73.3	69.8	60.0
Kütahya	7.9	44.9	41.0	38.3	29.7
Dazkırı/Afyon	—	24.2	24.0	23.7	22.9
Pamukkale/Denizli	—	7.1	6.9	6.9	6.5
Karapınar/Konya	—	7.5	6.1	—	—
Doğanhisar/Konya	—	43.4	43.0	42.4	40.8

Table A2: NO_2 hotspots and predicted maximum concentrations

Source: own

	Max Concentration of SO_2 (μg/m³)				
Location	2017 Base Year	2028 Current Policy	2028 New Policy	2028 Advanced Renewables A	2028 Advanced Renewables B
Bayramiç/Çanakkale	1.4	—	—	—	—
Akçakoca/Düzce	1.6	1.2	1.0	—	—
Yumurtalık/Adana	2.2	—	—	—	—
Afşin/Kahramanmaraş	—	2.9	2.7	2.5	2.2
Kütahya	—	1.5	1.4	1.3	1.0
Doğanhisar/Konya	—	1.5	1.5	1.5	1.4

Table A3: Primary PM hotspots and predicted maximum concentrations

Source: own

Location	Max Concentration of NO_2 (µg/m³)				
	2017 Base Year	2028 Current Policy	2028 New Policy	2028 Advanced Renewables A	2028 Advanced Renewables B
Dursunbey/Balıkesir	2.7	2.6	—	—	—
Bodrum/Muğla	10.5	—	—	—	—
Çeşme/İzmir	6.4	5.2	4.4	4.1	3.2
Kınık/İzmir	7.5	3.1	2.3	—	—
Bayramiç/Çanakkale	4.7	4.1	3.4	3.0	2.2
Emet/Kütahya	4.0	11.6	11.2	10.9	9.7
Osmaneli/Bilecik	—	4.5	4.3	4.1	3.7
Tepebaşı/Eskişehir	3.7	—	—	—	—
Beylikova/Eskişehir	4.4	—	—	—	—
Polatlı/Ankara	—	4.0	3.8	3.7	3.4
Bala/Ankara	2.3	3.7	3.4	3.2	2.9
Akçakoca/Düzce	8.9	16.9	14.4	13.1	10.6
Afşin/Kahramanmaraş	4.5	17.0	15.8	15.3	14.5
Yumurtalık/Adana	11.4	10.4	9.4	8.8	6.9
Dazkırı/Afyon	—	7.8	7.7	7.6	7.4
Doğanhisar/Konya	—	8.2	8.1	8.0	7.8

Table A4: Secondary PM hotspots and predicted maximum concentrations

Source: own

Location	Max Concentration of NO_2 (µg/m³)				
	2017 Base Year	2028 Current Policy	2028 New Policy	2028 Advanced Renewables A	2028 Advanced Renewables B
Çeşme/İzmir	3.8	4.1	3.8	3.6	3.0
Osmaneli/Bilecik	5.8	11.5	11.2	11.1	10.3
Bala/Ankara	2.3	3.3	3.3	3.2	2.9
Erbaa/Tokat	2.3	2.9	2.3	—	—
Yumurtalık/Adana	3.4	4.8	4.7	4.6	4.4
Pamukkale/Denizli	—	3.0	2.9	2.9	2.8
Karapınar/Konya	—	3.2	2.6	—	—
Polatlı/Ankara	—	2.9	2.8	2.8	2.6
Afşin/Kahramanmaraş	—	3.0	2.8	2.7	2.3

Table A5: CO hotspots and predicted maximum concentrations

Source: own

Annex 4: Dispersion modelling results

This section presents the CALPUFF modelling results for the air pollutants SO_2, NO_2, primary PM (directly emitted), secondary PM (formed in the atmosphere), and CO for the 2017 base year analysis and the four scenarios defined above. Coal, lignite, and natural gas-fired power plants are considered in these analyses.

Figure A12 to Figure A16 show contour plots of the average annual atmospheric SO_2 concentrations for the 2017 base year and the different scenarios. The results clearly show that power generation plants, particularly coal-fired ones, are major emitters of SO_2, resulting in a number of hotspots around coal- and lignite-fired power plants. The modelling results also clearly demonstrate that SO_2 levels at these hotspots decrease in the future scenarios with increased share of renewables in the electricity generation mix.

Figure A17 to Figure A21 show contour plots of the annual NO_2 concentrations for the base year and for the future power generation scenarios. The annual NO_2 air quality standard is 40 µg/m³. The results suggest that hotspots develop around individual power plants. However, except for areas very close to power plants, pollutant levels are lower than the allowable air quality levels. It is important to note here that the computed NO_2 impacts are due to electricity generation only. There are other major sources of NO_2, such as industrial activity and transportation, which also emit large quantities of nitrogen oxides. The combined effects of these sources together with electricity generation can be significant, particularly in urban areas. Increasing use of renewables can help alleviate these high concentrations.

Figure A22 to Figure A26 show contour plots of primary PM_{10} emitted directly from power plants for the base year and for the future power generation scenarios. The annual PM10 air quality standard is 40 µg/m³. As in the case for NO_2, hotspots develop around individual power plants. However, except for areas very close to the power plants, pollutant concentrations are lower than the Turkish air quality standards.

Figure A27 to Figure A31 show contour plots of secondary PM formed in the atmosphere from power plants emissions, for the base year and the future power generation scenarios. It is observed that the predicted secondary PM levels (mostly $PM_{2.5}$) are much higher than primary PM_{10} levels. Moreover, secondary PM, which is formed from emitted NO_x and SO_2 together with background ozone and ammonia, is spread over a much larger area because these smaller particulates tends to remain suspended in the atmosphere for longer periods of time. The predicted high levels of secondary PM, large spatial extent, and their associations with adverse environmental and health impacts indicate that they will impose a large disease burden. The use of more renewables in Turkey's electricity generation mix would reduce this adverse impact.

Figure A32 to Figure A36 show contour plots of average annual atmospheric CO concentrations for the 2017 base year and the different scenarios. The annual CO standard is 10,000 µg/m³. Although some hotspots develop around individual power plants, the average annual CO concentrations are significantly lower than the permissible air quality standard, indicating that electricity generation is not a major contributor of atmospheric CO.

SO_2 Concentration (µg/m³) for the Base Year 2017

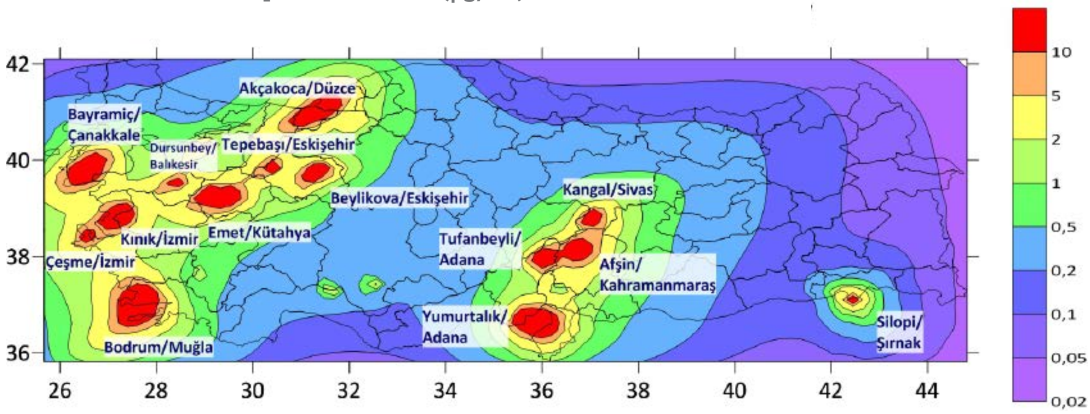

Figure A12: Predicted average annual SO_2 concentration for 2017

Source: own

SO_2 Concentration (µg/m³) for the Current Policy Scenario for 2028

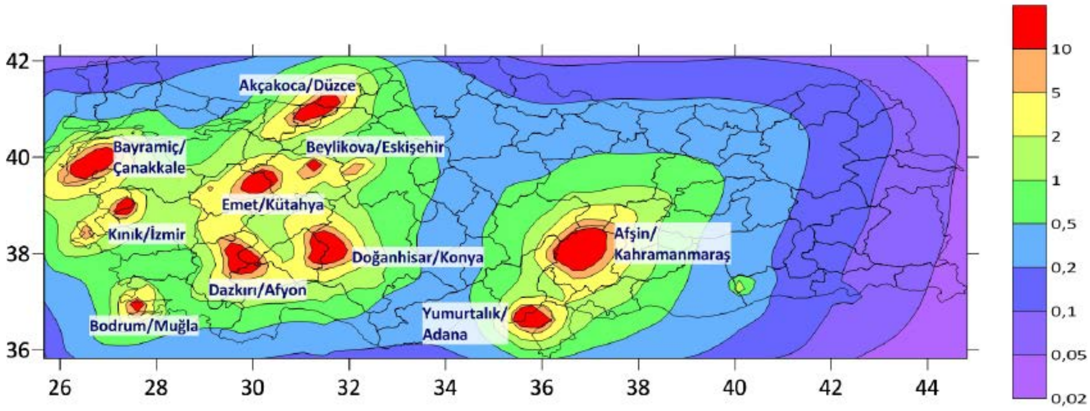

Figure A13: Predicted average annual SO_2 concentration: Current Policy Scenario for 2028

Source: own

SO_2 Concentration (µg/m³) for the New Policy Scenario for 2028

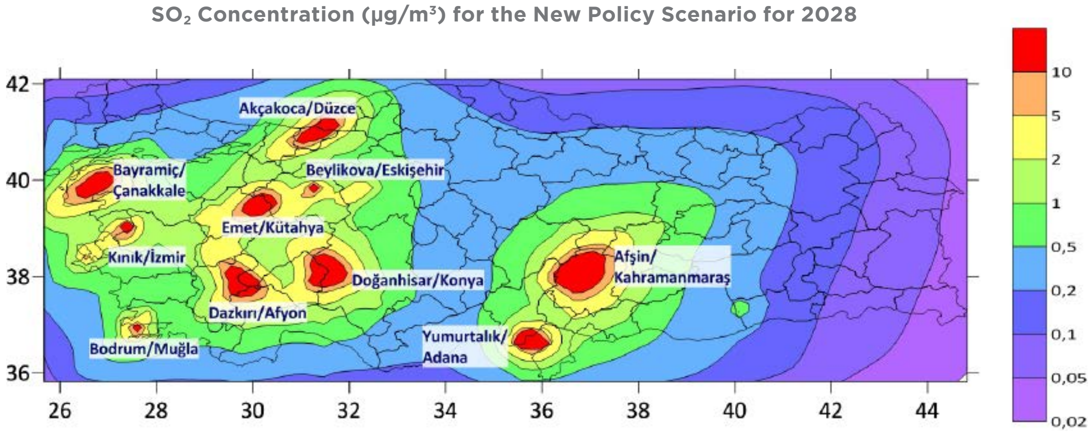

Figure A14: Predicted average annual SO_2 concentration: New Policy Scenario for 2028

Source: own

SO_2 Concentration (µg/m³) for the Advanced Renewables Scenario A for 2028

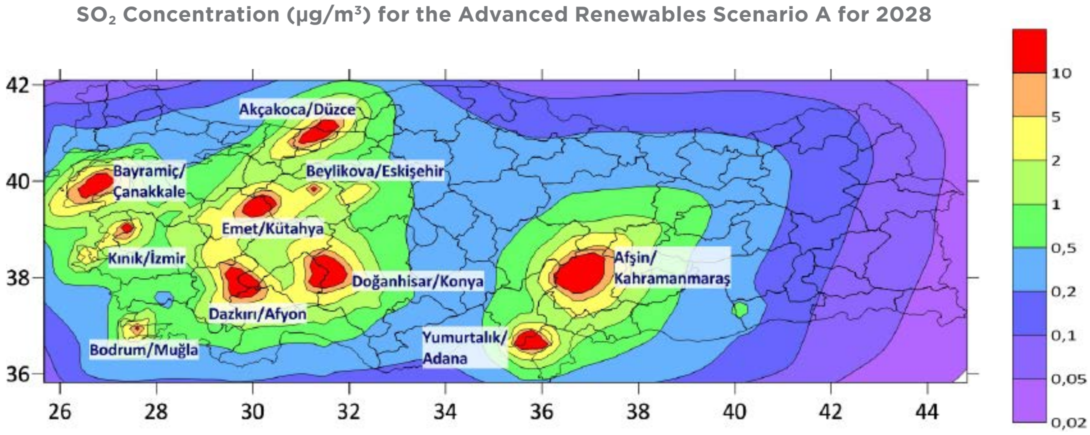

Figure A15: Predicted average annual SO_2 concentration: Advanced Renewables Scenario A for 2028

Source: own

SO_2 Concentration (µg/m³) for the Advanced Renewables Scenario B for 2028

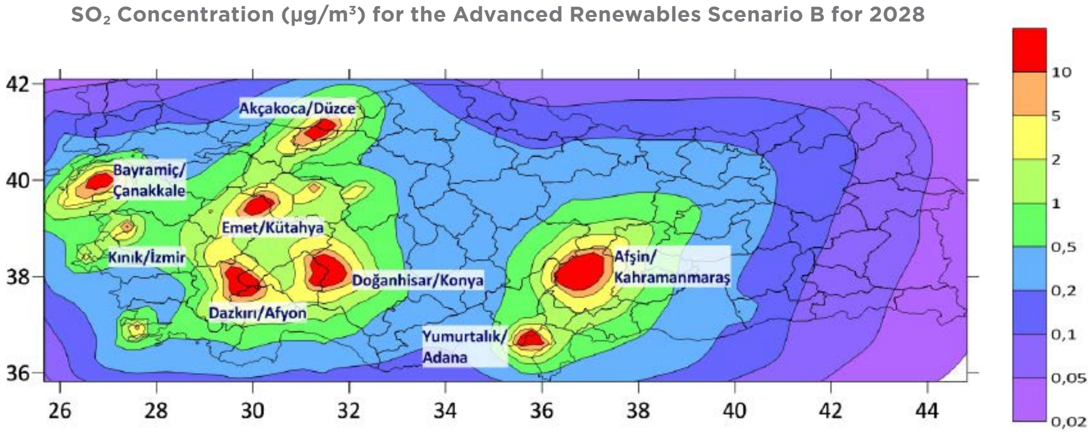

Figure A16: Predicted average annual SO_2 concentration: Advanced Renewables Scenario B for 2028

Source: own

NO_2 Concentration (µg/m³) for the Base Year 2017

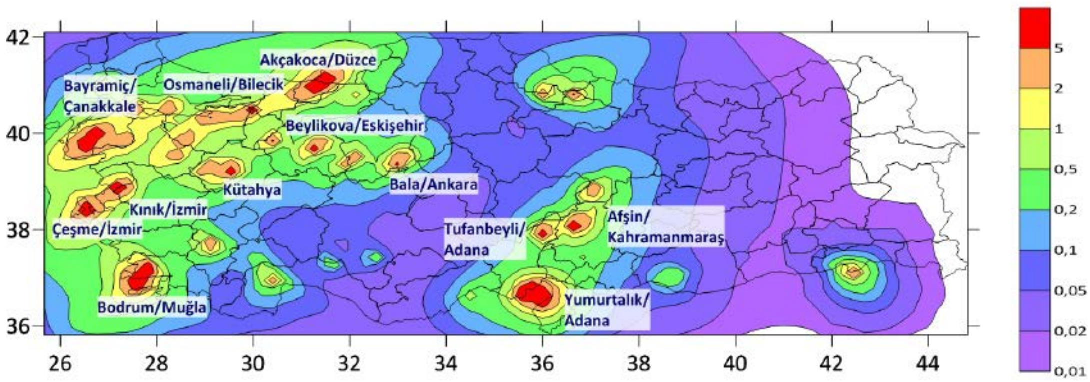

Figure A17: Predicted average annual NO_2 concentration for 2017

Source: own

NO$_2$ Concentration (µg/m^3) for the Current Policy Scenario for 2028

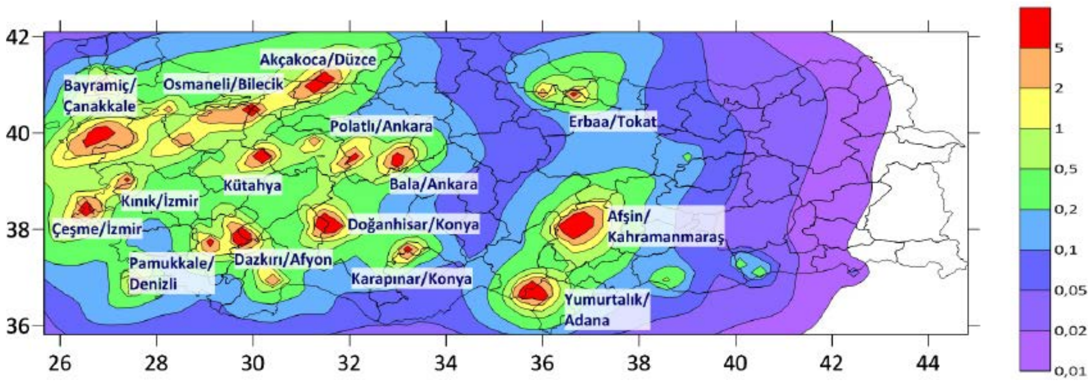

Figure A18: Predicted average annual NO$_2$ concentration: Current Policy Scenario for 2028

Source: own

NO$_2$ Concentration (µg/m^3) for the New Policy Scenario for 2028

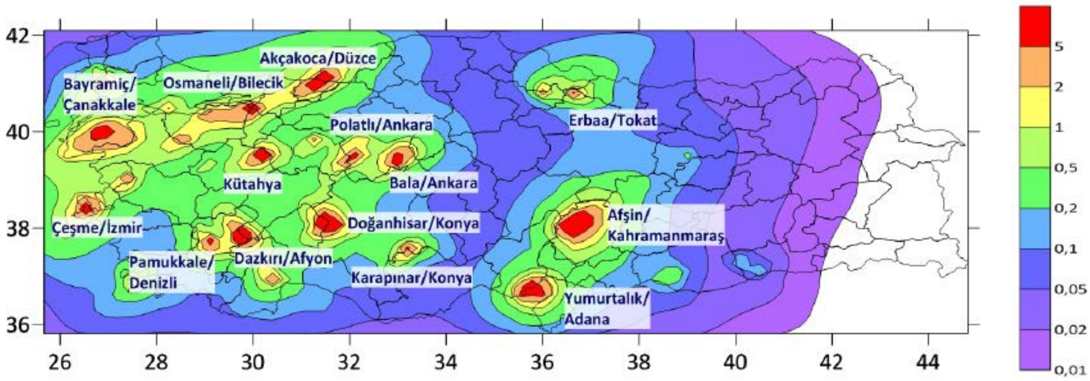

Figure A19: Predicted average annual NO$_2$ concentration: New Policy Scenario for 2028

Source: own

NO$_2$ Concentration (µg/m^3) for the Advanced Renewables Scenario A for 2028

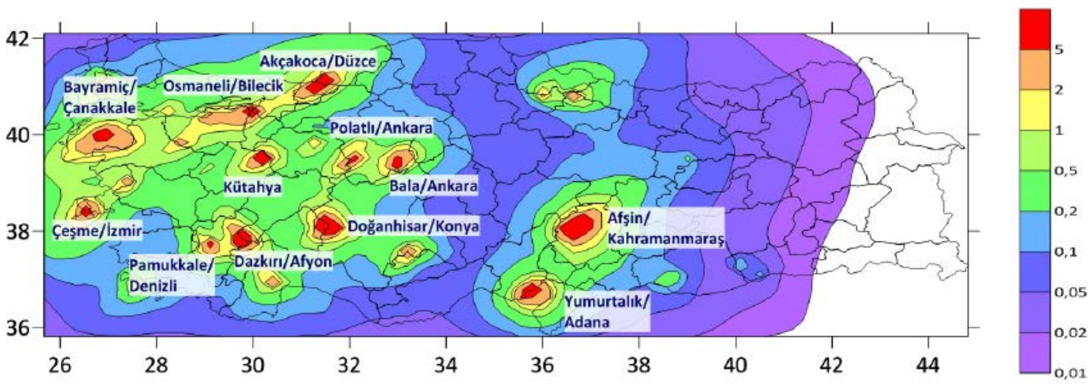

Figure A20: Predicted average annual NO$_2$ concentration: Advanced Renewables Scenario A for 2028

Source: own

NO_2 Concentration (µg/m³) for the Advanced Renewables Scenario B for 2028

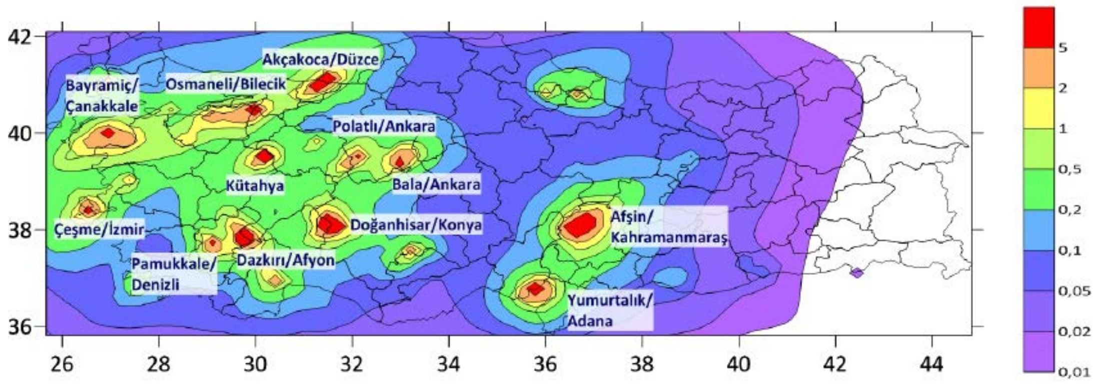

Figure A21: Predicted average annual NO_2 concentration: Advanced Renewables Scenario B for 2028

Source: own

Primary PM Concentration (µg/m³) for the Base Year 2017

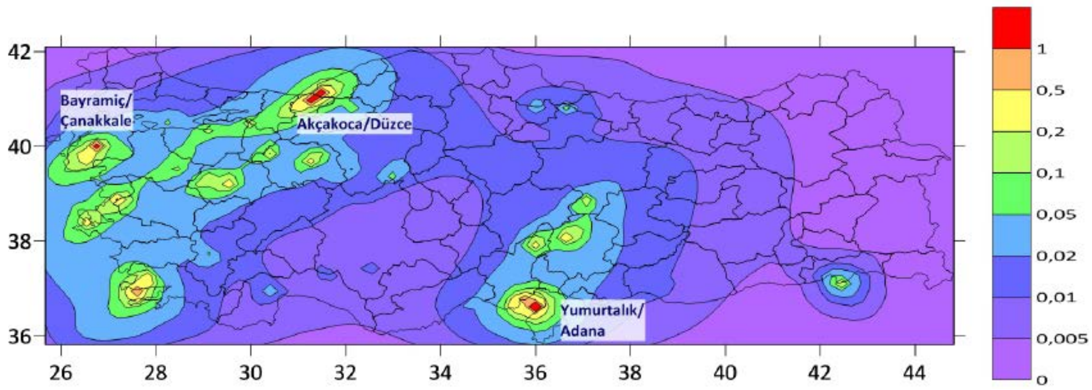

Figure A22: Predicted average annual primary PM concentration for 2017

Source: own

Primary PM Concentration (µg/m³) for the Current Policy Scenario for 2028

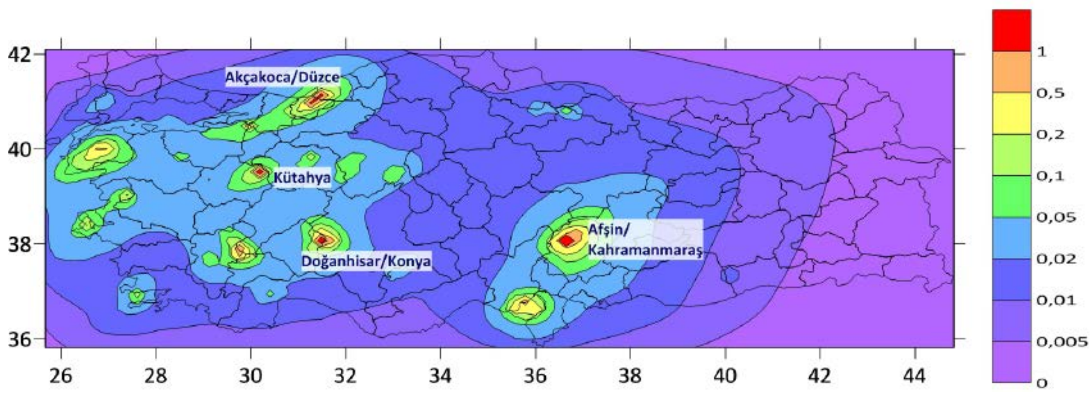

Figure A23: Predicted average annual primary PM concentration: Current Policy Scenario for 2028

Source: own

Primary PM Concentration (µg/m³) for the New Policy Scenario for 2028

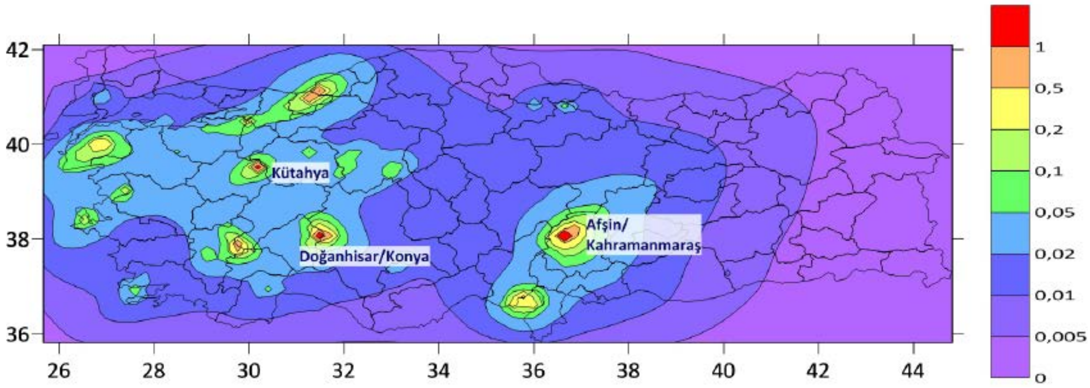

Figure A24: Predicted average annual primary PM concentration: New Policy Scenario for 2028

Source: own

Primary PM Concentration (µg/m³) for the Advanced Renewables Scenario A for 2028

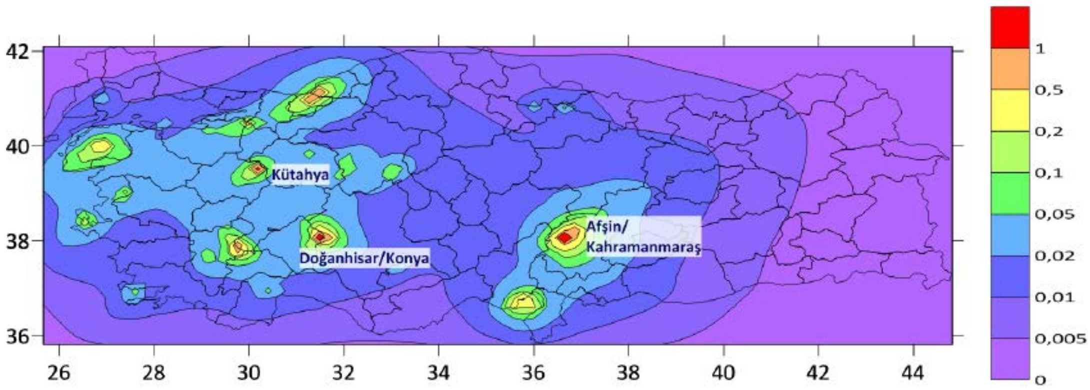

Figure A25: Predicted average annual primary PM concentration: Advanced Renewables Scenario A for 2028

Source: own

Primary PM Concentration (µg/m³) for the Advanced Renewables Scenario B for 2028

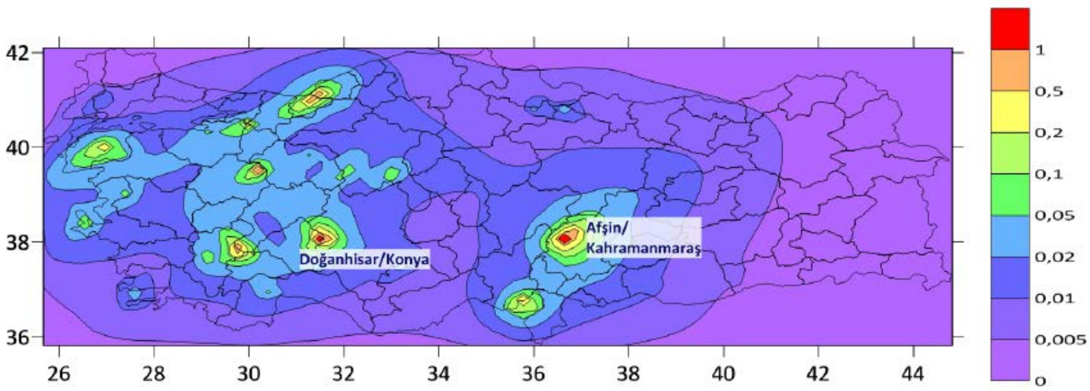

Figure A26: Predicted average annual primary PM concentration: Advanced Renewables Scenario B for 2028

Source: own

Secondary PM Concentration (μg/m³) for the Base Year 2017

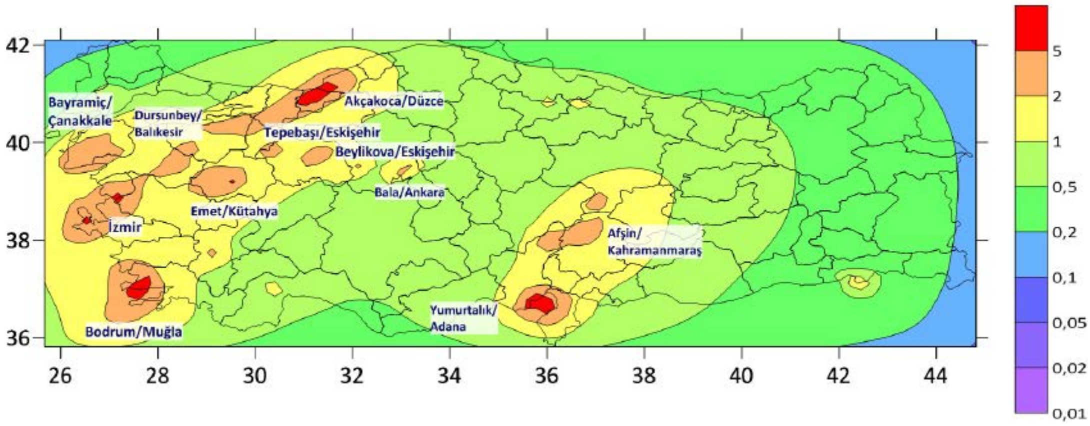

Figure A27: Predicted average annual secondary PM concentration for 2017

Source: own

Secondary PM Concentration (μg/m³) for the Current Policy Scenario for 2028

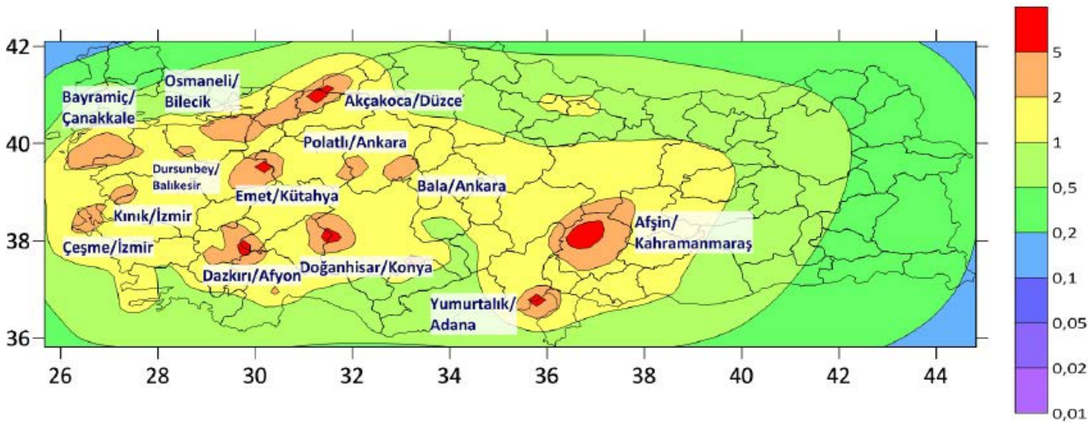

Figure A28: Predicted average annual secondary PM concentration: Current Policy Scenario for 2028

Source: own

Secondary PM Concentration (μg/m³) for the New Policy Scenario for 2028

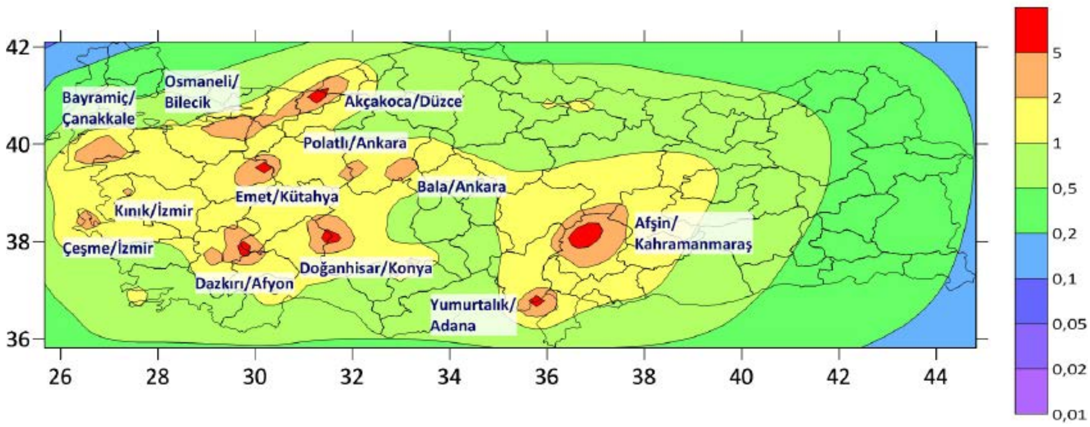

Figure A29: Predicted average annual secondary PM concentration: New Policy Scenario for 2028

Source: own

Secondary PM Concentration (μg/m³) for the Advanced Renewables Scenario A for 2028

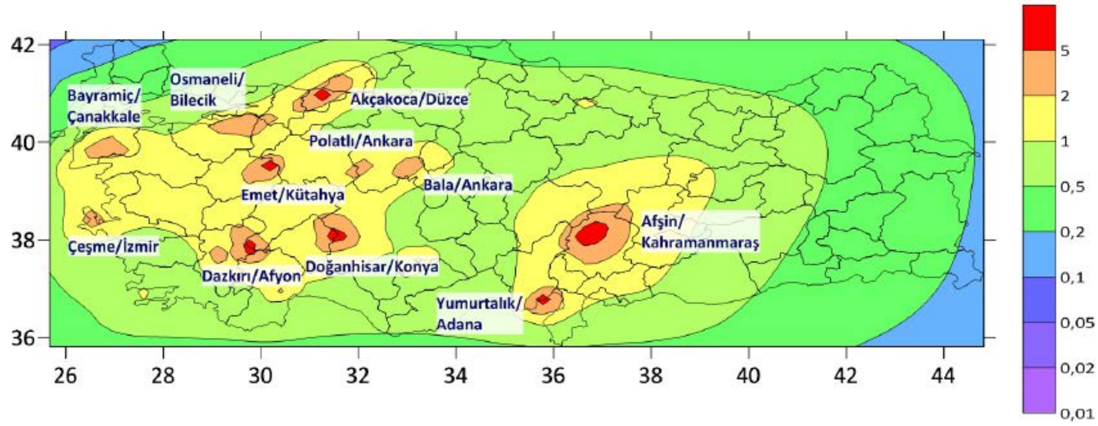

Figure A30: Predicted average annual secondary PM concentration: Advanced Renewables Scenario A for 2028

Source: own

Secondary PM Concentration (μg/m³) for the Advanced Renewables Scenario A for 2028

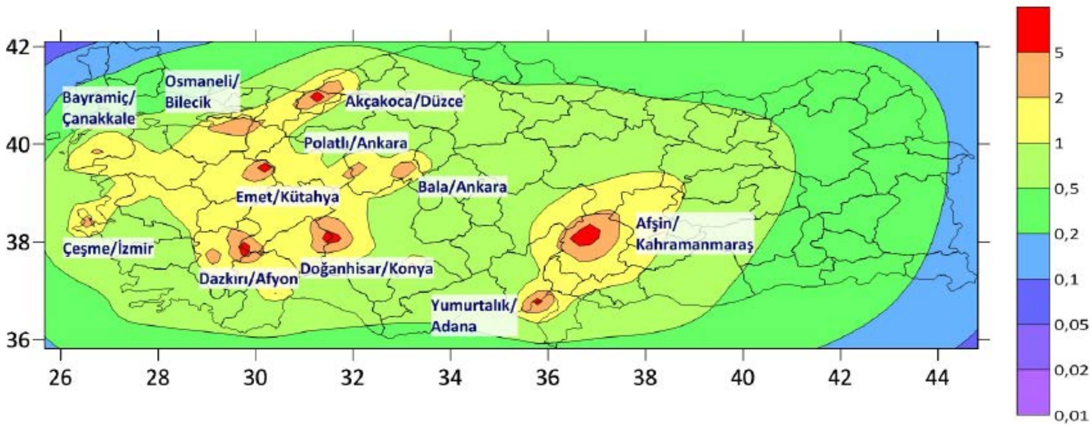

Figure A31: Predicted average annual secondary PM concentration: Advanced Renewables Scenario B for 2028

Source: own

CO Concentration (μg/m³) for the Base Year 2017

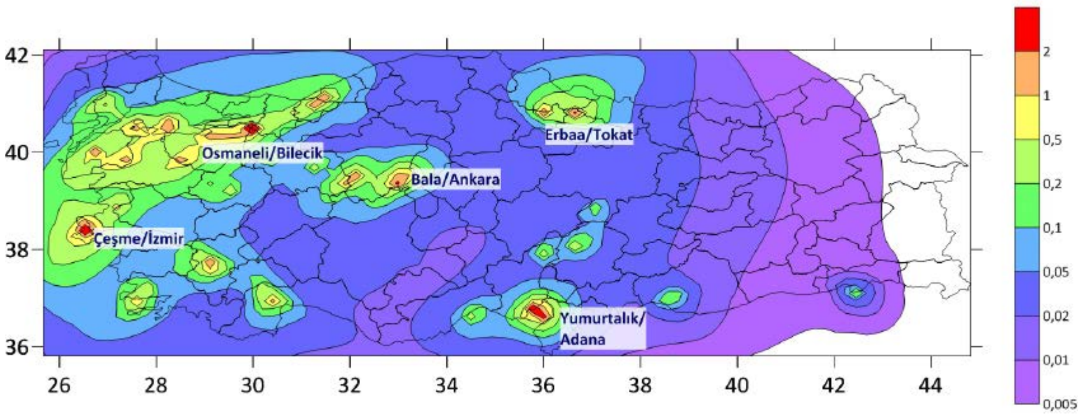

Figure A32: Predicted average annual CO concentration for 2017

Source: own

CO Concentration (µg/m³) for the Current Policy Scenario for 2028

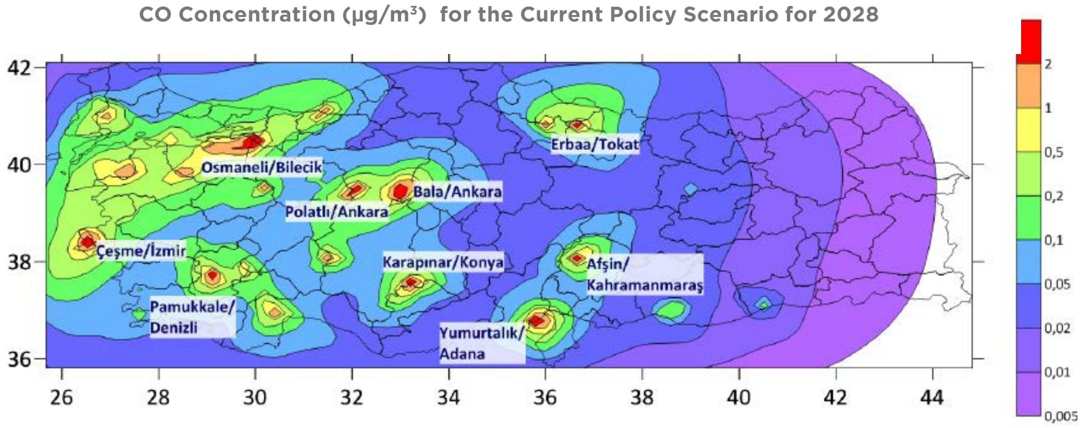

Figure A33: Predicted average annual CO concentration: Current Policy Scenario for 2028

Source: own

CO Concentration (µg/m³) for the for the New Policy Scenario for 2028

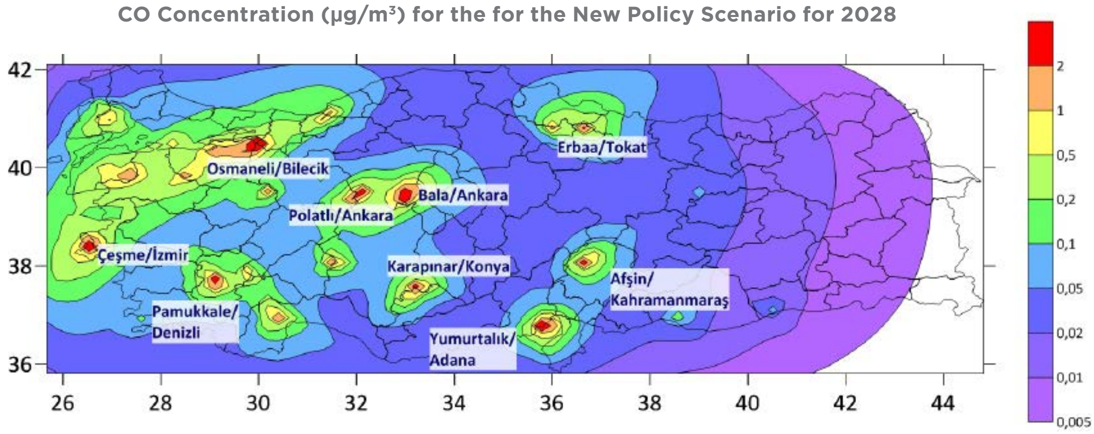

Figure A34: Predicted average annual CO concentration: New Policy Scenario for 2028

Source: own

CO Concentration (µg/m³) for the Advanced Renewables Scenario A for 2028

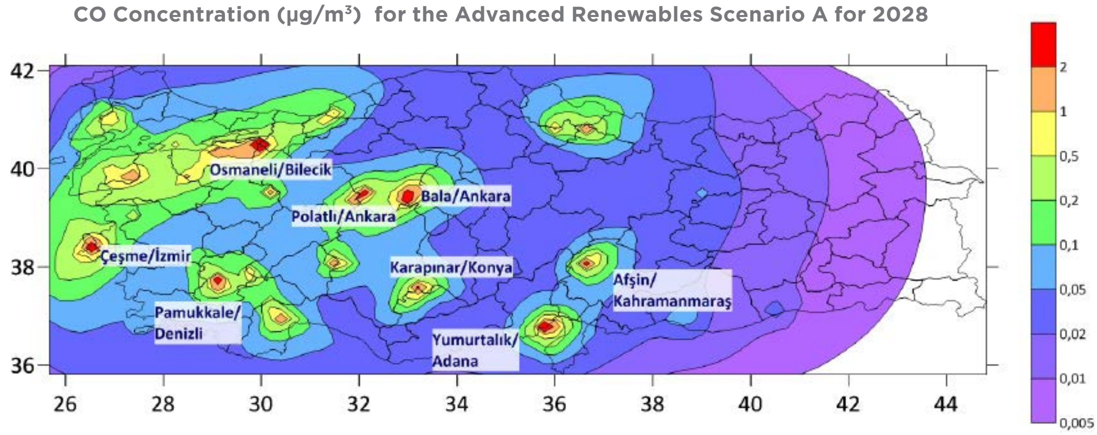

Figure A35: Predicted average annual CO concentration: Advanced Renewables Scenario A for 2028

Source: own

CO Concentration (µg/m³) for the Advanced Renewables Scenario B for 2028

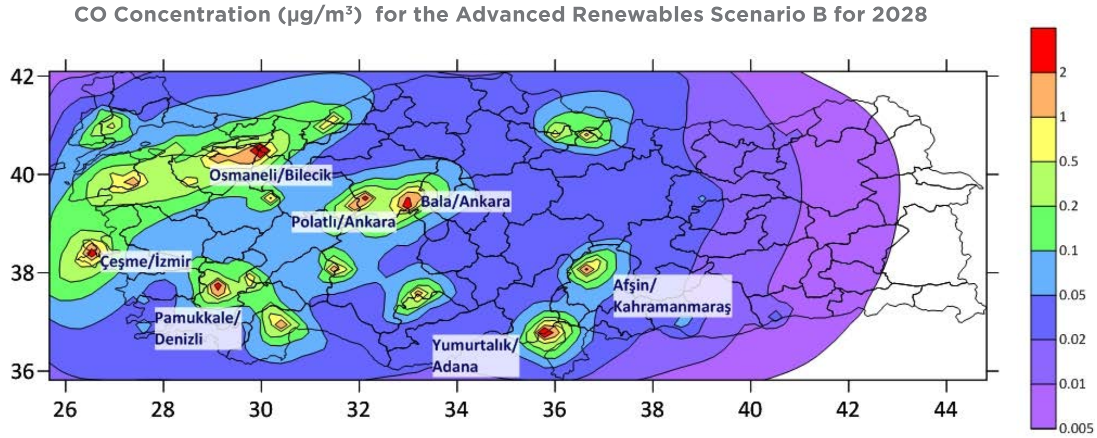

Figure A36: Predicted average annual CO concentration: Advanced Renewables Scenario B for 2028

Source: own

Annex 5: Detailed health costs due to air pollution in Turkey

Table A6: Detailed health costs due to air pollution under different scenarios (USD)

Source: own

		2017 Base Year	2028 Current Policy	2028 New Policy	2028 Advanced Renewables A	2028 Advanced Renewables B
	Chronic Bronchitis (PM)	67,703,617	**82,982,319**	73,776,063	68,796,939	57,689,622
	Restricted Activity Days (PM)	1,416,575	1,717,821	1,527,243	1,424,170	1,194,236
	Congestive Heart Failure (PM)	10,339,434	12,452,838	11,071,290	10,324,093	8,657,256
	Congestive Heart Failure (CO)	21,517	32,051	29,253	27,649	23,7601
	Lung Cancer (PM)	5,434,732	6,545,604	5,819,419	5,426,668	4,550,529
Hospital Admissions	Respiratory (PM)	559,577	673,957	599,185	558,747	468,537
	Respiratory (SO_2)	629,658	650,156	563,402	519,642	425,490
	Cerebrovascular (PM)	1,725,061	2,077,669	1,847,167	1,722,502	1,444,403
	Bronchodilator use (PM)	14,248,352	16,177,010	14,382,294	13,411,637	11,246,318
	Cough (PM)	126,367,075	143,472,143	127,555,002	118,946,354	99,742,377
	Lower respiratory symptoms (PM)	13,215,862	15,004,763	13,340,099	12,439,780	10,431,369
Asthma, Adults >15 yr	Bronchodilator use (PM)	97,528,239	119,537,475	106,275,703	99,103,188	83,102,905
	Cough (PM)	257,539,403	315,658,421	280,638,525	261,698,317	219,446,930
	Lower respiratory symptoms (PM)	25,192,717	30,877,966	27,452,291	25,599,545	21,466,480
Mortality	Acute Mortality (SO_2)	645,189,106	666,192,062	577,298,687	532,459,157	435,985,571
	Chronic Mortality YOLL (PM)	943,568,443	1,189,514,306	1,057,546,757	986,173,252	826,954,850
	Infant Mortality (PM)	7,076,827	7,795,745	6,930,866	6,463,104	5,419,632
HG Damage Cost		1,163,333	1,201,683	1,056,167	982,626	821,462

Improving livelihoods and unburdening the health system with renewables.

COBENEFITS

COBENEFITS
Connecting the social and economic opportunities of renewable energies to climate change mitigation strategies

COBENEFITS cooperates with national authorities and knowledge partners in countries across the globe such as Germany, India, South Africa, Vietnam, and Turkey to help them mobilise the co-benefits of early climate action in their countries. The project supports efforts to develop enhanced NDCs with the ambition to deliver on the Paris Agreement and the 2030 Agenda on Sustainable Development (SDGs). COBENEFITS facilitates international mutual learning and capacity building among policymakers, knowledge partners, and multipliers through a range of connected measures: country-specific co-benefits assessments, online and face-to-face trainings, and policy dialogue sessions on enabling political environments and overcoming barriers to seize the co-benefits.

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