A HOLISTIC VIEW OF CLIMATE CHANGE AND ITS IMPACTS IN TURKEY

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December 2013

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1. **INTRODUCTION**

1.1. Background and purpose of this report

The Earth’s climate is becoming warmer. Since the beginning of the twentieth century the global mean surface temperature has increased by about 0.89 °C. The fifth assessment report (AR5) of the Intergovernmental Panel on Climate Change (IPCC) states that this change is “extremely likely” due to human activities (IPCC, 2013). If people continue to emit greenhouse gasses into the atmosphere, at present or closer levels, temperatures are expected to rise further in the twenty first century. Based on different scenarios, climate scientists estimate increases between 1.5 and 4.5 °C by the end of the present century (IPCC, 2013).

Climate models that are used to carry out climate change scenario simulations suggest that the increases in greenhouse gasses affect not only surface temperatures but also all climate parameters from precipitation to sea level. The same climate models also indicate that the changes are not uniformly distributed around the world, and there are places where the impacts are larger than those in other areas. The Mediterranean Basin is one of these high impact regions, and therefore it is identified by the fourth IPCC report (IPCC, 2007) as one of the most vulnerable to future climate change. The major concern for this region is the simulated basin-wide reduction in precipitation, which is expected to aggravate the situation on the already scarce water resources.

Turkey is one of the countries in the basin that could be profoundly affected by this change. Temperature increase together with the changes in precipitation could have important consequences on the environment, society, and the economy in Turkey. Several factors including the distributions of population, industry, agriculture, water resources etc. may influence the distribution of the impacts of climate change. Turkey is highly region- alized in terms of each one of these factors. For this reason, the climate change and impact assessment studies usually choose to work on sub-regions such as basins and provinces. It could be stated that a study showing the whole picture at country scale is missing for Turkey.

This study, therefore, attempts to compile and analyze the existing data and studies to reveal a holistic picture of climate change and its effects in Turkey.

1.2. Structure of this report

Following this introduction, Section 2 describes the methodology and data used in this study. Section 3 provides background information about climate, its past, and the projected changes in Turkey. Section 4 reports on the potential impacts of future climate change on resources and important sectors in Turkey. Section 5 provides suggestions on how Turkey could cope with climate change. This section also gives conclusive information regarding the report.
2 METHODOLOGY AND DATA

2.1. Methodology

Climate change projections used in this study are based on the A2 scenario simulation of ECHAM5, the General Circulation Model (GCM) of the Max Planck Institute in Germany. Downscaling its outputs to a higher resolution (27 km) was achieved by employing a Regional Climate Model called ICTP-RegCM3, the regional climate model of the International Centre for Theoretical Physics in Trieste, Italy (Bozkurt et al., 2012; Önol et al., 2013). A2 is a high emission scenario that was used in the fourth Assessment Report of IPCC. According to the IPCC, “the A2 storyline and scenario family describes a very heterogeneous world with continuously increasing global population and regionally oriented economic growth that is more fragmented and slower than in other storylines.”

As for all scientific data, climate change projections involve certain levels of uncertainty. The primary sources of uncertainty are the emissions scenarios and the GCMs that are used to simulate them. It is difficult to anticipate how the world will change in the 21st century. Therefore the IPCC developed a variety of scenarios taking into account the driving forces such as demographic development, socio-economic development, and technological change. The future evolution of these scenarios is, however, highly uncertain. This problem could be partially overcome by using as many scenarios as possible in future climate change projections. Given the fact that this requires a lot of time and computational resources, most analyses on climate change at regional scale still rely on few scenario simulations. In this study, we selected a high emissions scenario, A2, with the intention that the simulations based on this scenario provide the upper bounds of the changes. The fifth IPCC report uses a different scenario family, called Representation Concentration Pathways (RCP), and the scenarios are identified by their approximate total radiative forcing in 2100 relative to 1750 (e.g., 8.5 W/m² for RCP8.5) (IPCC, 2013). The A2 scenario is similar to the RCP8.5 of the new scenario family of IPCC, which is also defined to provide the upper bounds of changes in the climate. On the global scale, the projections produced for these two scenarios are also very similar.

The development in GCMs during the last two or three decades has been enormous. Their validation with observations for the 20th century indicates that they are able to simulate the basic features of the climate of the Earth. They also thoroughly capture the global temperature increase during the last hundred years or so. However, they still have large spatial and temporal differences in their climate outputs, especially in precipitation. The most common way to eliminate some of the uncertainty coming up this way is to use the ensemble mean of GCM outputs in an analysis instead of using directly the outputs of a single GCM. This methodology is good when working directly with the GCM outputs or their statistically downscaled outputs, which could be easily obtained in a relatively short time. It is more difficult and costly to produce ensembles using dynamic downscaling methods, and therefore many dynamic downscaling studies involve a single (or a few) scenario simulation(s) in their future climate change assessments. Such assessments may therefore involve more uncertainty. Nevertheless, this methodology provides an enhanced assessment of areas in complex topography and landscape, as it resolves surface features that are usually omitted in the statistical methods. In this study, the ensemble means of the statistically downscaled simulations from a study (www.climatewizard.org) were also considered. However, the resolution (50
km) was deemed inadequate to address province scale changes in Turkey. Therefore, the present study utilized a dynamically downscaled higher resolution scenario simulation that was specifically produced for Turkey.

In this study hotspot analysis is used to identify the areas that are most important in terms of topics of interest. Thus, hotspot cities or basins are determined based on the average and standard deviation of the data of interest (e.g. population of the 81 provinces). If the values are larger than the average plus two standard deviations (average + two times standard deviation), then these cities or basins are specified as hotspots. For instance, Istanbul and Ankara are hotspots for population because the populations are larger than the average plus two times the standard deviation of all provinces.

2.2. Data

Many different data sets are used in this study. The observational precipitation and temperature data are obtained from the General Directorate of Meteorology. The water potential data is acquired from the State Hydraulic Works. The forest data is obtained from the General Directorate of Forestry. The demography and sector data (agriculture, tourism, and energy) are acquired from the Turkish Statistical Institution (TÜİK). The maps have been prepared on the Geographic Information System (ArcMap).
3 CLIMATE CHANGE IN TURKEY

3.1. Introduction

Turkey is a Eurasian country lying between the latitudes 36° and 42° N and longitudes 26° and 45° E. It is surrounded by seas on three sides: Black Sea to the north, Aegean Sea to the west, and Mediterranean Sea to the south. Turkey has a fairly mountainous landscape (Figure 1). It consists of a high central plateau that lies between two mountain ranges: the Pontic Mountain range to the north, and the Taurus Mountains to the south. The average elevation of Turkey is about 1,000 meters. The elevation increases eastward. Highlands of eastern Turkey comprise the headwaters of the important rivers such as Euphrates and Tigris. The coastal plains of Turkey are mostly narrow. However, there are a few exceptions that are formed by the relatively big rivers in Turkey. These large plains include Bağra and Çarşamba on the Black Sea coasts, Menemen and Balat on the Aegean Sea coasts, and Çukurova on the Mediterranean coasts.

Figure 1. Topography of Turkey. Also shown are the provinces of Turkey and meteorological station locations providing daily weather data.

Turkey is situated in the mid-latitudes, and therefore it is under the influence of westerly airflow with respect to the atmospheric general circulation. For this reason, the western-facing sides of mountain ranges and coastal areas receive, in general, more precipitation than the other sides. According to the Köppen-Geiger climate classification, there are three primary climate types in Turkey. The Mediterranean and Aegean coastal areas of the country experience a temperate Mediterranean climate, which is characterized by hot and dry summers and mild and wet winters. The Black Sea coastal region experiences the features of a temperate maritime climate, which are warm and wet summers, and cool and wet winters. The interiors of Turkey are under the influence of a continental climate, which has hot summers and cold winters.
winters. This region usually receives comparatively less precipitation, most of which is in the form of snow in winter.

Turkey is located in the eastern parts of the Mediterranean Basin, identified as one of the most vulnerable regions to climate change by the fourth Assessment Report of IPCC (IPCC, 2007). Likewise, Giorgi (2006) defined the Mediterranean region as one of the climate change “hotspots” in future projections. The General Circulation Model (GCM) simulations largely agree on a basin-wide precipitation reduction in the Mediterranean Basin (IPCC, 2007; IPCC, 2013). Some studies (e.g. Giorgi and Lionello, 2008) suggest that the Atlantic cyclone tracks will shift northward as a result of the strengthening of the subtropical high over the Mediterranean region. This change is expected to increase the precipitation in the Black Sea basin, while decreasing it in the Mediterranean basin. Based on the A2 scenario simulation of NASA’s fvGCM model, Önel and Semazzi (2009) investigated future climate change over the eastern Mediterranean for the last 30 years of the 21st century. They reported drying for the Mediterranean and Aegean coastal regions of Turkey, while wetting for the Black Sea coastal areas. Gao and Giorgi (2008) also reported a similar pattern of precipitation change. Moreover, Hemming et al. (2010) indicated that the magnitude of precipitation decrease (5%-25%) for all the model ensembles was highly consistent in the western coasts of Turkey during the first half of the 21st century. Evans (2009) examined future predictions of 18 GCMs over the Middle East, and showed that the largest precipitation decrease (annually more than 25%), caused by less storm track activity over the eastern Mediterranean, would occur over southwestern Turkey in 2095. The projected annual discharges by Kitoh et al. (2008) indicated substantial decreases for the Euphrates River (30-70%) for the end of the 21st century, as a result of the reduction in precipitation over the basin. Bozkurt and Sen (2013) suggest that the annual surface runoff in the headwaters of the Euphrates and Tigris Basin will decrease between 25% and 55% by the end of the century. Their study also indicates that the peak flow timing in this basin will shift to earlier days by 18-39 day. Fujihara et al. (2008) conducted a detailed hydrological study for the Seyhan River Basin, which covers the large downstream Çukurova Plain, to determine the potential impacts of climate change. This study uncovered that the annual runoff, which was calculated from the precipitation and evapotranspiration variables of two different GCMs, would decrease between 50% and 60% for the entire basin. Sensitivity studies were conducted to identify the climatic effects of the surrounding seas of Turkey. Bozkurt and Sen (2011) also indicated that warmer summer and autumn sea surface temperatures of the surrounding seas of Turkey would probably enhance the formation of the flash floods and extreme precipitation events. Such a severe precipitation event took place in Istanbul in September 2009, and resulted in the loss of more than 30 lives and a large concentration of property. Önel et al. (2013) report the results of the most comprehensive climate change downscaling study on Turkey, which includes the analysis of the three different scenario simulations of three different GCMs. The present study uses one of the scenario (A2) simulations that are reported in Önel et al. (2013).

Several projects have been carried out to understand and project climate change and its effects for Turkey. The pioneering project entitled “Climate change scenarios for Turkey,” which was funded by the Scientific and Technological Research Council of Turkey (TÜBİTAK), used MPI’s (Max Planck Institute) ECHAM5 global circulation model scenario simulations to produce relatively high resolution outputs for Turkey. The outputs of this project were used in the First National Communication to UNFCCC (United Nations Framework Convention on Climate Change) of Turkey on climate change in 2007. A similar follow-up project, which was supported by MDG-F (Millennium Development Goals - Achieve-
ment Fund) through UNDP-Turkey (United Nations Development Programme), helped broadened the spectrum of the available high resolution simulations by downscaling the climate change projections of the CCSM3 model of NCAR (National Center for Atmospheric Research, USA) and HadCM3 model of the Hadley Centre, UK. The high-resolution outputs from both studies are made available through a data dissemination system on a web portal (agora.itu.edu.tr). The Second National Communication of Turkey on climate change, which was recently released (as the second-to-fifth National Communication), has benefitted considerably from the outputs of both projects. Moreover, these projects have caused the initiation of some climate change impact assessment studies in Turkey. “Turkey’s Tomorrows”, a project that was funded by a Turkish food company called Eti-Burçak, was carried out by WWF-Turkey (World Wildlife Fund), and DHI (Danish Hydraulic Institute). This project investigated the future of water resources and grain production in the Konya Basin, an endorheic one in the interiors of Turkey. With financial assistance from MDG-F through UNDP-Turkey, the State Hydraulic Works and DHI have carried out a project entitled “Identification of surface water resources potential and flood risks within the perspective of developing water resources management policies in Seyhan Basin within the framework of adaptation to climate change.” The final report of this study indicates that climate change will adversely affect the water resources and agriculture in Seyhan Basin, which feeds one of the main cotton production plains (Çukurova) in Turkey. Other impact assessment projects are also focused on the individual basins or provinces in Turkey. The present study, albeit not as detailed, aims to provide an integrated picture of some of the future climate change impacts for Turkey.

The following two sections provide more information about the climate of Turkey, how it changed during the last 50 years, and how it is expected to change in the future.

### 3.2. Climate observations

The climate analysis of Turkey is based on approximately 230 meteorological stations distributed across the country (Figure 1). It is apparent that the density of station network on the mountainous areas is much lower than that on the coastal and other low-lying or relatively flat regions. This poses a problem in obtaining a reliable distribution of the climate parameters, which is especially more serious in the case of precipitation.

#### 3.2.1. Temperature

Figure 2 illustrates the distributions of the observed annual temperatures (°C) averaged for the period between 1961 and 1990. The spatial distribution of temperatures broadly reflects the effect of topographic elevation. The coastal areas and the low-lying land areas in the westernmost parts are warmer than the central plateau and the eastern highlands. In winter months, the climate is relatively cold in much of Turkey, including the central and eastern parts (usually below 0 °C), yet it is relatively mild along the coastal areas due to sea effect (usually over 4 °C). In summer, monthly average temperatures rise over 25 °C on the Mediterranean and Aegean coastline and southeastern Turkey. They are slightly lower along the Black Sea coastline (about 21 °C). The summer temperatures in the central plain and the eastern highlands are also well above 20 °C. Thus, the temperature ranges in a year, based on monthly averages, are about 18 °C for the Black Sea coastline, about 20 °C for the Mediterranean coastline, about 23 °C for the central plateau and about 30 °C for the eastern parts of Turkey.

#### 3.2.2. Precipitation

Figure 3 illustrates the distributions of the observed annual precipitation (mm) averaged for the period between 1961 and 1990. Turkey receives much of its precipitation in the colder months. The coastal regions receive more precipitation than
Figure 2. Observed annual temperature 1961-1990. Data source: General Directorate of Meteorology.

Figure 3. Observed annual precipitation 1961-1990. Data source: General Directorate of Meteorology.
the interior areas. The seasonality of precipitation increases as one goes from the Black Sea coastline, which receives precipitation in almost all months, to the Mediterranean coastline, which is mostly dry in summer. The eastern Black Sea coastal region could get as much as 2,500 mm annual precipitation. On annual basis, the precipitation amounts are about 850 mm for the Black Sea coastline, about 730 mm for the Mediterranean coastline, about 400 mm for the central plain and about 580 mm for the eastern parts of Turkey.

3.2.3. Past changes

Figure 4 illustrates the past changes in the hydro-climatic variables. Temperatures are rising almost everywhere in Turkey. The summer temperatures have increased more than the temperatures in other seasons (not shown). The average summer temperature of 2000s is about 1.5 °C higher than that of 1960s or 1970s. Spring and fall temperatures have also increased in recent decades, but the increases are not as high as that in summer. Precipitation has not changed significantly in Turkey except for the northeastern parts where it shows a consistent regional increase. The observations indicate important changes in two more hydro-climatic variables (mountain glacial retreat and streamflow timing), which could be considered as a response to increasing temperatures. A study by Sarıkaya (2011) suggests that the mountain glaciers in Turkey have been retreating at a rate of about 10 m/year. The eastern Anatolian highlands, which feed important rivers such as Euphrates and Tigris, are covered by snow during the cold period, and the snow starts to melt in March when the temperatures rise over freezing point in the region. The recent warming is causing snow to start melting earlier, and this could be observed in the stream discharges as they start to rise earlier in response to this event. Studies by Sen et al. (2011) and Yucel et al. (2013) analyzed the discharge data in the unregulated basins in the

Figure 4. Past changes in temperature, precipitation, sea level, river discharges, and mountain glaciers. For data source see the text.
As mentioned earlier, the future climate analysis of Turkey is based on a CMIP3 simulation that was used in the fourth Assessment Report of IPCC. The projection involves the simulation of the ECHAM5 General Circulation Model. The results that are being reported here are the dynamically down-scaled outputs (temperature, precipitation, wind speed, and solar radiation) of ECHAM5 model. The emissions scenario used in this simulation is A2, which could be classified as a high emissions (pessimistic) scenario. There are two target periods: a 30-year period in the mid-century (2041-2070) and a 30-year period at the end of the century (2071-2099). The projections presented below are the averages of these 30-year periods.

### 3.3. Future projections

As mentioned earlier, the future climate analysis of Turkey is based on a CMIP3 simulation that was used in the fourth Assessment Report of IPCC. The projection involves the simulation of the ECHAM5 General Circulation Model. The results that are being reported here are the dynamically down-scaled outputs (temperature, precipitation, wind speed, and solar radiation) of ECHAM5 model. The emissions scenario used in this simulation is A2, which could be classified as a high emissions (pessimistic) scenario. There are two target periods: a 30-year period in the mid-century (2041-2070) and a 30-year period at the end of the century (2071-2099). The projections presented below are the averages of these 30-year periods.

#### 3.3.1. Temperature projections

Figure 5 shows the changes in the annual temperatures of the mid-century and end-century with the

### In summary, the historical changes in the climate of Turkey are as follows:

- **Temperatures** have been increasing everywhere. Summer temperatures have seen the most increase; the warm season expands,
- **Precipitation** has increased in the northeastern parts,
- **Mountain glaciers** have been retreating (about 10 m/year),
- **Timing of the peak discharges** is shifting to earlier days,
- **Sea level** has been rising at different magnitudes in the surrounding seas of Turkey, and
- **The number of natural hazards** seems to rise with increasing temperatures.

region and assessed that the peak discharge timing has already shifted to earlier days. The magnitude of the shift they calculated is about 7-10 days. There are few studies that address the sea level rise in Turkey. It is not directly related to climate change in Turkey, but the observations show that sea level is rising between 3.8 and 7.7 mm/year (Demir et al., 2005).

In Turkey, General Directorate of Meteorology records the number of natural hazards of meteorological origin, such as droughts, floods, tornados, severe precipitation events, storms, etc. The statistics show that the 1960s and 2000s experienced the highest number of natural hazards. On the other hand, the number of natural hazards was relatively low in 1980s. It is worth mentioning that the temperature change over this period, i.e. between 1960 and 2010, was fairly correlated with the change of the number of natural hazards that occurred in Turkey. This suggests that when temperatures are higher than average, a higher number of natural hazards is expected.

The changes are not uniformly distributed. The eastern and south-eastern parts of Turkey illustrate comparatively larger increases in temperatures. The seasonal changes indicate that summer temperature increases are much larger than winter temperature increases in Turkey (not shown). Some studies (e.g. Önol et al. 2012) suggest that the number of hot spell days (the days with the largest number of consecutive days where the daily maximum temperature is larger than 30 °C) will increase substantially in the southeast Anatolian region and coastal areas of the Mediterranean region by the end of the present century.

1961-1990 period as reference. According to the A2 scenario simulation, the temperatures in Turkey are projected to increase between 1.0 °C and 2.5 °C by the mid-21st century and between 2.5 °C and 5.0 °C by the end of the century. The changes are not uniformly distributed. The eastern and south-eastern parts of Turkey illustrate comparatively larger increases in temperatures. The seasonal changes indicate that summer temperature increases are much larger than winter temperature increases in Turkey (not shown). Some studies (e.g. Önol et al. 2012) suggest that the number of hot spell days (the days with the largest number of consecutive days where the daily maximum temperature is larger than 30 °C) will increase substantially in the southeast Anatolian region and coastal areas of the Mediterranean region by the end of the present century.

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- **Temperatures** have been increasing everywhere. Summer temperatures have seen the most increase; the warm season expands,
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- **Timing of the peak discharges** is shifting to earlier days,
- **Sea level** has been rising at different magnitudes in the surrounding seas of Turkey, and
- **The number of natural hazards** seems to rise with increasing temperatures.
3.3.2. Precipitation projections

Figure 6 shows the changes in the annual precipitation of the mid-century and end-century with the 1961-1990 period as reference. The projections indicate that the annual precipitation will tend to decrease in the southern parts of Turkey while it will tend to increase in the northern parts, especially in the northeastern parts. The reductions along the Mediterranean coastlines could be as large as 20% by the mid-century and 30% by the end of the century. Similar magnitudes could be stated for the increases along the northeastern coastal areas of Turkey. As mentioned earlier, Turkey receives much of its precipitation in winter, and winter precipitation is projected to decrease across much of the country, especially along the Mediterranean coastlines.
coastal region, probably in response to fewer and weaker storm activity in the region. The uncertainty in precipitation estimations is usually high. However, the 16-model ensemble average available from all CMIP3 simulations broadly agrees on the aforementioned changes. These changes also agree broadly with the changes reported in other similar studies, which may even include different emissions scenarios such as A1B and A1FI. The more optimistic scenarios such as B1 yield very similar spatial patterns of precipitation change, but with smaller rates (Önol et al. 2012). Furthermore, the projections of the CMIP5 simulations, which are reported in the fifth Assessment Report (AR5) of IPCC (IPCC, 2013), depict a fairly similar change pattern for Turkey.

Figure 6. Future precipitation changes over the 1961-1990 period: (a) 2041-2070 period, (b) 2071-2099 period.
3.3.3. Wind projections

Figure 7 shows the changes in the annual wind speed of the mid-century and end-century over the 1961-1990 reference period. According to the calculations based on the meteorological observations, the northwestern parts of Turkey have the highest wind potentials in Turkey. It could be said that the wind potential in these areas will increase in the future. The wind speeds in the Marmara region and northwestern parts of Aegean region are projected to increase up to 15% by the mid-century and up to 20% and more by the end of the century. They are also predicted to increase substantially in the western central areas including Ankara, Konya, and Kirikkale provinces. On the other hand, the wind speeds are simulated to decrease in the eastern parts of Turkey.

Figure 7. Future wind changes over the 1961-1990 period: (a) 2041-2070 period, (b) 2071-2099 period.
3.3.4. Solar radiation projections

Figure 8 shows the changes in the annual solar radiation of the mid-century and end-century over the 1961-1990 reference period. The climate change projections indicate that the solar radiation will slightly increase in much of Turkey. The increase will be up to 3% by the mid-century and up to 6% by the end of the century. The latter will occur mostly in the western half of Turkey. In the future, there may be some decreases in the solar radiation of the eastern Black Sea coastal areas.

Figure 8. Future solar radiation changes over the 1961-1990 period: (a) 2041-2070 period, (b) 2071-2099 period.
3.3.5. Sea level rise projections

Since the beginning of the 20th century, global sea level rise was estimated to be approximately 190 mm (IPCC, 2013). According to the model-based projections, it is estimated to increase between 260 and 820 mm in the 21st century (IPCC, 2013). Using tide gauge measurements between 1972 and 2009, Öztürk (2011) reported that the annual average increase rate of sea levels along the Mediterranean and Aegean Sea coasts of Turkey is about 1.57 mm/year. Comparable rates are reported for the Black Sea coasts of Turkey (e.g., Karaca and Nicholls, 2008). The study by Karaca and Nicholls (2008) characterizes Turkish coastlines as exhibiting low to medium vulnerability to a 1m rise in sea levels. Figure 9 shows the coastal areas that are at risk from coastal inundation as a result of a rise in sea level, storm surge, and tidal range, based on a 10m scenario. It should be noted that the area threatened by the sea level rise is quite small compared to its total land area. The 10m scenario indicates that the deltas of the major rivers are primarily at risk. These plains include Çarşamba (the delta of Yeşilırmak) and Bafra (the delta of Kızılırmak) on the Black Sea coast, Menemen (the delta of Gediz) and Balat (the delta of Büyük Menderes) on the Aegean Sea coasts, and Çukurova (the delta of Seyhan and Ceyhan) on the Mediterranean coasts. These plains are particularly important for agriculture in Turkey. The projected sea level rise also seems to affect the important coastal cities such as Istanbul, Izmir, and Antalya.

Figure 9. Low-lying coastal regions (in red) are at risk from coastal inundation as a result of sea level rise, tidal range, and storm surge (10m scenario). Based on topography of Turkey.
In summary, the projected changes in the climate of Turkey for the future are as follows:

- **Temperatures** will increase ubiquitously in all seasons, but the increases will be higher in summer than in winter,
- **Precipitation** will decrease in the southern parts of Turkey. It may slightly increase in the northeastern parts,
- **Wind potential** will increase in the northwestern parts of Turkey. It may decrease in the eastern parts,
- **Solar radiation** will increase across the country, but the increases will be larger in the western parts,
- **Sea level rise** is expected to impact the low-lying areas of the river deltas and coastal cities,
- The changes in the climate parameters will likely increase the **water stress**,
- The **landslide** risk is high at the northeastern parts of Turkey. The projected increase in precipitation for this area could enhance the frequency and intensity of the landslides, and
- Overall, the intensity and duration of **droughts** and **hot spells** could increase in response to increasing temperatures and decreasing precipitation in Turkey.
The future changes in climate are likely to have significant implications for resources as well as important sectors in Turkey. This study attempts to qualitatively assess some of the direct impacts on human and water resources and agriculture, forest, tourism, and energy sectors. The province or basin based data for these resources and sectors are used to obtain hotspots, which are then evaluated using the projections of temperature, precipitation, wind speed, and solar radiation. Table 1, which shows the sensitivities of resources and sectors to climate variables and hazards, was formed based on expert judgment on direct impact. Temperature increase, precipitation change, drought, heat waves, and wildfires are the top changes or hazards that will affect the resources and sectors in Turkey in the future.

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There are some studies that identify some of the possible risks and opportunities climate change may represent for the resources and sectors in Turkey. A climate change impact assessment project undertaken in 2009 “Turkey’s Tomorrows” supported by ETİ Burçak, a Turkish food company, concluded that the usable water in the central Konya Basin, which produces most of Turkey’s grain, would decrease significantly during this century. This project has led to a number of initiatives and campaigns to raise awareness on climate change impacts in the Konya Basin. Using the Turkish tourism sector as a further example, climate change has the potential to create both opportunities and threats. Turkey’s Mediterranean coastline, which attracts millions of tourists every year, is projected to have much higher temperatures, especially in the summer season, and significantly less rainfall in the future. Although the changes in climate may bring positive benefits for the tourism industry, by extending the tourism period and increasing the number of tourists per season, the sector will have to consume additional energy for cooling and more water for domestic and irrigation purposes. Therefore, the critical question is whether water resources in the region can meet the future requirements of individual and public consumers.

In view of the projected changes provided in earlier sections, below we will qualitatively assess the possible impacts of climate change on the aforementioned resources and sectors in Turkey.
4.1. Impacts on people and living conditions

The Turkish population is highly concentrated in certain regions (Figure 10). In general the coastal areas of Turkey are more populated than the interior lands. A large portion of the population lives in Istanbul and nearby cities. Izmir, Ankara, Bursa, and Adana are some other cities with a high concentration of population. Istanbul and Ankara are the hotspot cities in terms of population.

Regionalization increases the vulnerability to natural disasters, whether they are related to climate change or not. The most populated cities of Turkey including Istanbul have experienced significant water shortages in 2007-2008 when they fell under the influence of severe drought conditions. Droughts and heat waves are the two most important climate change related hazards that could negatively affect the urban life of Turkey in the future. Downpours that could be produced as a result of the excess heating of the surface could also carry serious threats by causing urban floods. A downpour in September 2009 causing torrential rainfall severely hit a highly industrialized area of Istanbul, causing more than 30 deaths and millions of dollars in damage.

There may also be positive effects of climate change to human life in the future. The projections indicate that the Mediterranean climate will prevail in more areas of Turkey including Istanbul. Many people may favor such a change, as the Mediterranean climate is popular and more accommodating. However the exposure to higher summer temperatures may create uncomfortable conditions for the elderly, children, and those with health problems. In the regions where both temperature and rainfall are projected to increase, the outbreaks of some diseases like malaria and sandfly may also increase.

Figure 10. Province based population density in Turkey (shade). Also shown are the province based population according to 1990 census (red bar), and the changes in the population from 1990 to 2000 (green bar) and from 2000 to 2011 (yellow bar).
4.2. Impacts on water resources

The useable water in Turkey is about 112 billion m$^3$ per year. Currently, about 40% of this amount (i.e. 44 billion m$^3$) is utilized. Most of this water is used for agricultural irrigation (33 billion m$^3$).

The useable water amount may seem quite high, but it does not make Turkey a water rich country. As a matter of fact, it is classified as a “water stressed” country because the per capita water amount is about 1,500 m$^3$, which is quite low compared to many other European countries. This number is projected to become even smaller in the future whether the climate change is considered or not.

If we assume that the amount of useable water does not change throughout the 21st century (i.e. no climate change effect), the per capita water amount will decrease to 1,200 m$^3$ in 2050, because the population will increase (TUIK estimates that the population will increase to around 93 million in 2050). As TUIK projects a smaller population for 2075 (82 million), the per capita water amount will slightly increase to about 1,250 m$^3$ that year.

Climate change projections indicate that the precipitation Turkey receives will decrease in the future, which will result in a reduction in the water resources, hence the amount of useable water. In this case, the above numbers for the per capita water amounts will become even smaller. Based on a pessimistic scenario (A2), the model projections indicate that there will be 16% and 27% reductions in the water potentials in Turkey by 2050 and 2075, respectively. If we consider these numbers instead of assuming constant usable water throughout the present century, we will have about 1,000 m$^3$ water per capita in 2050 and about 915 m$^3$ in 2075. These numbers will place us amongst the category of “water scarce” countries.

The map in Figure 11 shows the changes of water potentials for individual basins in Turkey. It seems that there will be substantial reductions in the southern basins, while little or no changes in the northern basins occur. The changes in the southern basins may have important implications for the energy and agricultural productions in these basins.

4.3. Impacts on agriculture

Agriculture is one of the top sectors in Turkey. The climates of Turkey are suitable to grow a wide variety of crops, vegetables, and fruits. Most of the crops including wheat, barley, and rye are grown in the central plains (e.g. Konya).

Most vegetables and fruits are produced in the coastal cities of Turkey. One of the recently emerging agricultural spots of Turkey is the Harran Basin in southeast Anatolia, where it becomes possible to grow cotton and corn, in addition to wheat, barley, beans, and fruits. This has become possible after the Southeast Anatolian Project (GAP) brought Euphrates’s water to the arable lands of the plain.

Despite the prominence of the agricultural sector, the land sustainability for rain-fed agriculture is not high in Turkey. The yield per hectare is also low (for instance, wheat yield in Turkey is less than one third of what it is in Belgium). Given these factors and the projections, it could be said that climate change will adversely affect agriculture in Turkey. The map in Figure 12 shows that the hotspot cities for some of the top crops and fruits of Turkey overlap with the areas where the projections show decreases in rainfall. Thus, it could be stated that climate change will increasingly threaten the food security of Turkey in the 21st century.
Figure 11. Water potential changes in the basins of Turkey. The blue bar shows the water potentials based on the observations of State Hydraulic Works. The green and red bars show the projected water potentials for the mid-century and the end of the century, respectively.

Figure 12: Areas of crops, vegetables, and fruits in the 81 provinces in Turkey. The dotted provinces are the hotspots: Yellow dotted provinces are hotspots for crop cultivation; green dotted provinces are hotspots for vegetable cultivation; and red dotted ones are hotspots for fruit plantation.
4.4. Impacts on forests

Forestry is not a big sector in Turkey, although it has a sizeable forest cover, which accounts for roughly 21.5 million hectares (amounting to about 27% of the total area of Turkey). Half of the forest cover is classified as productive, and the other half as degraded. Turkey’s forests are mostly located in the areas that receive annual rain of more than 600 mm and as Figure 13 shows, these areas lie primarily along the seaside areas of Turkey.

Previous forest fire counts indicate that the forests along the Mediterranean, Aegean, and Marmara regions are already at high risk. The number of forest fires increases substantially in hot summer days when these areas, characterized by a typical Mediterranean climate, receive little or no rain.

As the climate change projections indicate that the temperatures will continue to rise, while rainfall decreases, we could expect more forest fires in these areas in the future. The areas with a fewer number of fires may also be subjected to more forest fires in the future. It will be highly difficult to sustain the present forest cover, especially in the southern and western parts of Turkey, when the air gets warmer and dryer.

Figure 13. Productive and degraded forest covers in the provinces of Turkey (forest cover/province area). Also shown are the present time and projected future (end-of-century) 600 mm isohyets (line of equal precipitation). Hatched provinces are hotspots in terms of forest cover.
4.5. Impacts on tourism

Turkey is one of the top tourism destinations in the world.

- Every year more than 30 million people visit Turkey. Most of them come from Germany and Russia.
- Turkey has a long shoreline along the Mediterranean and Aegean seas, making beach tourism extremely popular. In general, the western half of Turkey has the highest accommodation capacity. Antalya and Muğla, two southwestern coastal cities, come at the top of the list in terms of the number of beds (Figure 14).
- Turkey is also rich with historical and cultural sites that attract a considerable number of tourists every year.
- Turkey is a mountainous country and there are many places that are suitable for winter tourism, which has also experienced some momentum in recent years with the increases in the investments in this sector.

Increasing temperatures will most likely positively affect sun and beach tourism in Turkey. They will likely extend the tourism season by lengthening the warm season. They may also cause an increase in the shorelines in the north that are suitable for beach tourism.

On the other hand, the same increasing temperatures will negatively affect winter tourism, as they will melt the snow and reduce the snow cover in the future.

Figure 14: Number of beds in the provinces that are licensed for tourism by the Ministry of Culture and Tourism, Turkey. Hatched provinces are hotspots in terms of number of beds.
4.6. Impacts on energy

The total installed power in Turkey is about 58,000 MW as of April 2013. About 35% of this is from hydraulic power, 4% from wind power, and the rest (61%) is from fossil fuel (coal, natural gas, etc.) power. As Turkey does not have large fossil fuel reserves, it depends highly on their imports from other countries. In recent years Turkey has been increasing the part of renewable energy in the total installed power by investing in hydraulic, wind, solar, and geothermal energy. The map in Figure 15 shows installed powers in the 81 provinces of Turkey. Most of the hydraulic power plants are installed in the eastern parts of Turkey where the hydraulic potential is high. Most of the thermal power plants, however, are established in the northwestern part of Turkey where much of the population and industry is located.

Turkey has a total of 35,000 MW hydraulic potential. The present installed power is about 20,000 MW, so it has 15,000 MW more potential to utilize. However, it becomes increasingly difficult to utilize this potential as the constructions of power plants meet with resistance from the public as they carry progressively more threats to the environment. The future climate change projections indicate reductions in water potentials of the major basins of Turkey, such as Euphrates and Tigris, which will adversely affect the power generation from hydraulic resources in the future.

The installed wind power in Turkey is about 2,400 MW as of April 2013. Another 600 MW is under construction. According to the General Directorate of Renewable Energy, Turkey has about 48,000 MW wind energy potential (8,000 MW high efficient plus 40,000 MW medium efficient). Much of the potential lies in the western parts of Turkey, especially in Çanakkale, Balıkesir, and Izmir provinces. The climate change projections indicate that the wind potential will increase in the northwestern part of Turkey where it is already high.

The solar energy potential in Turkey is pretty high. The estimations place it around what the current total installed power in Turkey could produce. There have been recent investments to utilize this potential. As an indication of how attractive it is to invest in this sector, we could mention a recent (June 2013) tender that attracted a total of 8,900 MW applications for a total of 600 MW solar energy licenses. The climate change projections indicate a slight increase in the future for solar energy potential across Turkey.
Figure 15. Installed powers in the provinces of Turkey (as of 2011). Hatched provinces show the hot-spots (blue hatches are for hydraulic, and green hatches is for wind).
CONCLUSION AND SUGGESTIONS

5.1. Conclusion

The primary objective of this report is to provide a holistic picture on climate change and its possible impacts in Turkey. Turkey is a mountainous country surrounded by seas at its three sides, which allow several climate types resulting in an extremely diverse flora including a sizeable forest cover. The high elevation attribute helps Turkey to have a considerable precipitation and snow cover in winter, which melts in spring feeding the rivers. The water is held in the dam reservoirs to generate electricity and irrigate agricultural fields. Turkey has a sizeable population, which is about 75 million. Turkey’s long shorelines and rich historical and cultural heritage attract millions of tourists every year.

Besides all these positive attributes, which are very beneficial in the development of Turkey, there are some developments in recent decades that have increased the risks in Turkey. The rapid increase in population, for instance, has reduced the per capita water amount to the level classified as “water stressed”. Migration from eastern cities to western cities has resulted in a highly unevenly distributed population across the country. Both population increases and migration have caused substantial pressure on water resources in the western parts of Turkey. Istanbul, which is the top preferred city for migrants, has suffered from water scarcity from time to time since its water resources are very limited. This has prompted the authorities to build pipelines to transfer water to Istanbul from increasingly distant basins. Migration from the countryside to cities has also caused unplanned urbanization, and this has led to intensification of the urban heat island effect in the cities. The land sustainability for rain-fed agriculture in Turkey is not high. In fact it is low to moderate, so the agriculture sector, which is one of the most important sectors in Turkey, depends increasingly on irrigation.

There is no doubt that climate change will exacerbate the aforementioned and other possible risks and vulnerabilities because Turkey lies in an area that is projected to be one of most vulnerable areas to climate change in the world. The rise in temperatures and the decline in precipitation will increase the aridity in Turkey. There will be a decrease in Turkey’s water resources in the future. The per capita water amount will decrease to the level classified as “water scarcity” at country scale. If the present time distribution of population does not change in the future, the per capita water amounts will be quite low in the basins in the western half of Turkey. The southern basins will also be affected from climate change, as the precipitation, hence runoff, will be substantially reduced in these basins, where the allocation of water into energy generation, irrigation, domestic and industry use will have to be reconsidered. Solutions to water depletion in some basins that involve the transfer of water from nearby basins will certainly cause tensions amongst the residents of the basin whose water is moved out. This may result in an increase in “resource appropriation” in the future. For the transboundary rivers such as Euphrates and Tigris, the future reduction in the water levels may lead to an increase in “resource nationalism” in the upstream countries including Turkey.

The rain-fed agriculture will be adversely affected, as the climate change will likely increase the aridity and droughts in Turkey. The already relatively low yields in crop cultivation may, therefore, decrease further in the future. The droughts in the recent years are considered as the main reason for the high food prices in the world, which are threatening the “food security” in many countries. These countries whose land sustainability for rain-fed agriculture is low are mostly located in the latitudes just in the
south of Turkey. Climate change will likely result in a northward expansion of arid areas and yield increases in the intensity, frequency, and/or duration of droughts in Turkey. The 2007 drought that affected the western half of Turkey and the 2008 one that affected the southeastern part resulted in relatively lower yields in some crops in those years. The deficient part was met by imports from other countries. However, high food prices, which resulted primarily from the low yields in the main crop producing countries due to droughts, affected the country budget negatively. There is no doubt that such cases, which may occur more in the future, will increasingly threaten the “food security” in Turkey.

Turkey will be likely to be subjected to more heat waves and hot days and nights that will adversely affect the living conditions, especially in big cities. The 2003 heat wave in Europe is held responsible for the death of thousands of people. Global warming will likely increase the chances of such instances to occur, not only in Turkey but also every country that lie in the mid-latitudes of the world. Although the living conditions will be positively affected by the spread of the popular Mediterranean climate to more areas in Turkey including Istanbul, the heat waves together with the intensified urban heat will likely bring uncomfortable episodes to daily human life. Such conditions will harden, even threaten, the life of elderly, children, and people with health problems. Heat waves and hot days will also provide more suitable conditions for wildfire ignition. Consequently, the number of wildfires and the area they affect will most likely increase in the future.

5.2. Suggestions

The fragile situation of Turkey in terms of climate change makes it necessary for Turkey to act sooner rather than later in order to combat the adverse effects of climate change. The following list includes some suggestions:

- Mitigation is important to combat climate change at a global scale, so the activities in this endeavor must continue. However, Turkey should be ready for the worst-case scenario, and develop ASAP adaptation strategies, which will certainly make Turkey more resilient to climate change impacts.

- Despite substantial changes in the climate parameters, the resources of Turkey will most likely be adequate at the country scale in the future. The wellbeing of the country will, though, depend highly on how these resources are managed. In this regard, it could be said that all Turkey needs is good governance.

- Wasting is unfortunately common in water and energy use in Turkey. First and foremost, Turkey needs to learn how to limit such wasting, which definitely increases the vulnerability to climate change. Saving water will avert the adverse conditions in difficult times, such as drought. Saving energy will eliminate the need to build more power plants whose emissions strengthen the climate change.

- The population distribution is highly regionalized at different spatial scales in Turkey, which increases the susceptibility to natural hazards. A more distributed population across the country should be encouraged with the correct policies.

- The infrastructure of the cities should be adjusted to recycle a maximum amount of water to reuse it, for instance, in the irrigation of the parks.
• Turkey uses much of its usable water in the field of agricultural irrigation to meet the high demand due to the widely adopted flood irrigation method. It is necessary to reduce the water partitioned to agriculture by supporting and incentivizing water efficient irrigation techniques.

• Turkey should extend the fields where the water efficient irrigation techniques are used.

• Cropping patterns should be determined by taking climate change into account.

• Drought events, whose frequency, duration, and intensity may increase in the future, have the potential to threaten food security by affecting very large areas. Turkey should distribute the crop cultivation to different regions as much as possible to avert the adverse conditions such events could cause.

• It is becoming increasingly important to be able to do global scale drought monitoring. Droughts may affect major crop fields in the world and cause shortages in the yield. In response food prices rise. It will be highly valuable to be able to foresee this ahead and take necessary steps earlier to compensate the negative impact.

• Increasing temperatures threaten the forest resources of Turkey by causing forest fires. One way to combat this is to extend or replace the forest areas with drought and temperature resilient trees.

• The renewable energy portion in the total installed power in Turkey is comparatively high (close to 40%), thanks to the state’s aggressive hydraulic energy investments, but the actual energy production from the renewable sources within the total is not that high (close to 25%) as a result of the intermittent nature of the sources. Despite this adverse situation, Turkey must continue to explore and utilize its renewable potential to the utmost level as long as the stable energy supply is achieved.


by multiple GCMs over the Eastern Mediterranean–Black Sea region.” *Climate Dynamics* (in press).


A HOLISTIC VIEW OF CLIMATE CHANGE AND ITS IMPACTS IN TURKEY

ÖMER LÜTFİ ŞEN