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Climate Change Effects and Sustainability Needs

The Case of Morocco

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Foreword

Morocco's geographical location is both a curse and a blessing. The kingdom's natural borders are the Atlantic Ocean and the Sahara. Both will expand as a result of climate change and either flood or dry up the livelihoods of thousands of Moroccans. Many are already being driven from the countryside to large urban centres such as Casablanca. In 2022, Morocco experienced the longest period of drought in more than 40 years, which resulted in serious crop failures and real price explosions for agricultural products.

Moroccans will continue to feel the effects of climate change in the coming years, particularly in the form of water shortages. According to calculations by the World Bank[1], the amount of sustainably available water per inhabitant has fallen from more than 2500 cubic metres in 1960 to just 600 cubic metres in 2020. This means that Morocco is on the verge of sliding from an unproblematic supply situation to a state of water emergency within half a century.

On the other hand, Morocco has immeasurable potential for renewable energy. This is thanks to the high level of solar radiation, the reliable trade winds in the south and—albeit increasingly less—the water flowing from the Atlas Mountains. According to an estimate[2] by the German Society for International Cooperation (GIZ), Morocco could cover its entire electricity needs with hydro, wind and solar energy in the medium term and at the same time export surplus energy, for example in the form of green hydrogen.

Morocco pursues an ambitious climate and environmental policy. The country already covers almost 20% of its electricity needs with renewable energy. If all installed capacities were utilised, this figure could even rise to almost 40%. By 2030, more than half of the electricity is to be generated by water, wind and sun. This makes the kingdom a leader among developing countries and an important partner

[1] https://www.banquemondiale.org/fr/news/press-release/2022/07/20/moroccan-economy-slows-in-wake-of-drought-and-commodity-price-rises.

[2] https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2021/March/Renewable-Energy-Transition-Africa_Country_Studies_2021.pdf?la=en&hash=46D8ADDF378CD917C90F85F899B3F2B33A787CB8.

in the international fight against climate change. A highly professional academic community and an extraordinary active civil society support this ambition.

This book is the product of the 4th edition of the International Congress on Climate Change (CI2C_2023) on the topic of "Climate, Security and Development: Challenges and Opportunity for a Just Transition" which took place in Essaouira, on 24–26 October 2023, organised by the International Center for Research and Capacity Building (Centre International de Recherche et de Renforcement de Capacités, CI2RC, Essaouira, Morocco), the Friedrich Naumann Foundation for Freedom (FFN, Germany), the ENERGIES 2050 international association (France) and the Higher School of Technology of Essaouira, Cadi Ayyad University (ESTE, UCA, Morocco). This congress gathered researchers from a dozen countries and provided the authors of this book with a platform to present and discuss their findings and hypotheses.

May this book also inspire you and provide you with new insights and perspectives.

Enjoy the read!

February 2024

Sebastian Vagt
Director
Friedrich Naumann Foundation for
Freedom Morocco
Rabat, Morocco

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Part I
Climate Observation and Prediction in Morocco

Chapter 1
Exploring Climate Change: Morocco in Focus

Kholoud Kahime, Abdelali Boussakouran, Moulay Abdelmonaim El Hidan, and Mohamed El Yamani

Abstract Manifestations of climate change have been occurring more frequently in recent years, posing major challenges that require that require measures, and even strategies, for adaptation and mitigation. This review starts by providing an overview of climate change, focusing first on defining key concepts and understanding the emergence of associated events beyond natural phenomena. The causes of these changes are then explored, with a heightened emphasis on human-induced factors, including the contribution of industrial activities, agricultural practices, burning of fossil fuel, and greenhouse gas emissions responsible for global warming. Afterwards, the various possible future evolutions of these changes were presented, addressing fundamental principles, scenario construction models, as well as their similarities and differences. This first part concludes by an analysis of the repercussions of such changes on water resources—currently considered the most affected environmental element and will continue to face more impacts—along with water-related sectors and their vulnerability in the face of these challenges. The second part of this review highlights climate change in Morocco, beginning with the country's particular climatic features based on its topography and geographical location. Future

The original version of the chapter has been revised: The corresponding author and the sequence of the authors have been updated. A correction to this chapter can be found at https://doi.org/10.1007/978-3-031-59603-2_13

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projections are produced on the basis of previous scenarios, mainly for temperature and precipitation, to gauge the extent of climate change at national level. Subsequently, the repercussions of changes that have already occurred, as well as potential impacts resulting from future changes, are examined with a particular focus on the water, agriculture, and food security sectors. In fact, the rise in temperatures, coupled with irregularity and decreased precipitation, have led to a 35% reduction in surface compared to the period of 1940–1970 and a 60-m decline in piezometric levels in certain aquifers. These changes significantly impact water supply, especially for the agriculture sector, which heavily relies (87%) on rainfall conditions, putting food security at risk. Overcoming these critical situations will require substantial efforts, especially as the driving factors are expected to worsen.

Keywords Climate change · Anthropogenic factors · Water resources · Agriculture · Morocco

Introduction

Climate change is currently recognized as a significant global concern for humanity. This is evident in the shifting weather patterns, which play a crucial role in the development and growth (Bazzaz and Sombroek 1996; Hirich et al. 2016).

In Morocco, climate change is a significant challenge, as it is in all Mediterranean countries. Indeed, according to Rochdane et al. (2014), North African countries, including Morocco, are projected to be heavily impacted by the negative consequences of climate change. This includes further decreases in precipitation and increases in temperature, as indicated by Simonneaux et al. (2015) and Tramblay et al. (2014a, b). Its effects include environmental deterioration, reduced agricultural output, and heightened concerns over water, food availability and economic and societal stability in these regions (Ouhamdouch et al. 2018; Trabelsi and Zouari 2019; Bahir et al. 2020; Schilling et al. 2020).

Focusing on Morocco, a rising temperature trend has been well recorded over the past 30 years, exceeding the global average (+ 0.42 °C/decade on average since 1990 for Morocco versus + 0.28 °C/decade for all countries) (Woillez 2019). As for rainfall, El Ajhar et al. (2018) noted a shift over the period 1980–2015 towards drier conditions. These changes have led to disastrous natural phenomena such as drought, flooding, salinization, silting, etc. (Bouaicha and Benabdelfadel 2010). As a result, there is increasing pressure on natural resources, especially those used by the agricultural sector, which is integral to Morocco's economic, social, and environmental development, contributing 13–14% to the country's GDP (Abdelmajid et al. 2021). In relation to water resources, crucial for agricultural production, Morocco is currently classified as one of the countries with high water stress (Mason et al. 2019). In fact, water availability in Morocco has declined from over 2500 m^3 per person in 1960, to 730 m^3 per person in 2005 and 650 m^3 per person in 2015, and is expected to drop below 500 m^3 by 2030 (Mason et al. 2019; Bennouna 2020).

Risks of food insecurity, conflict and population displacement can increase under severe water scarcity and drought conditions. Coastal flooding from sea-level rise, environmental degradation, deforestation and loss of biodiversity and ecosystem services pose serious challenges to current development initiatives, leading to a significant increase in vulnerability to risks and hazards. Hence, there is a growing importance attached to the implementation of sustainable adaptation and resilience measures (USAID 2016).

The objective of this review is to conduct a comprehensive analysis of the evolution, impacts, and challenges associated with climate change, both on a global level and with a specific focus on the Moroccan context. We initiate our examination by exploring fundamental concepts, history, and evolution of climatic events, as well as the diverse factors contributing to climate change. Subsequently, we provide readers with a nuanced understanding of models and future projections of this complex phenomenon. Our review extends beyond a simple presentation of facts and statistics related to climate change, moving towards an in-depth discussion of the resulting impacts on crucial sectors, along with adaptation and mitigation challenges. In the second section, attention turns to the national level, highlighting first meteorological characteristics and their specific future projections. This exploration concludes by examining the repercussions of climate change on the water sector and its related activities, while analyzing their influence on agriculture and food security. Furthermore, we address the complex challenges that arise, requiring adaptation and attenuation strategies to cope with these major changes.

Comprehensive Insights into Global Climate Change

History and Meaning

Climate change refers to a long-term disruption of the Earth's climate and weather patterns. It includes changes in temperature, precipitation, wind patterns and other climatic factors (Kumar et al. 2018). These modifications can be ascribed to both natural processes and human activities. Actually, the Intergovernmental Panel on Climate Change (IPCC) defines climate change in the broadest sense as "any change in climate over time, whether due to natural variability or human actions". However, discussions on climate change in the recent decades have mostly focused on linking it to human-induced alterations. This is especially evident in the rise of greenhouse gas emissions resulting from activities like the combustion of fossil fuels, deforestation, and industrial processes. In fact, the Framework Convention on Climate Change (FCCC) specifically characterizes climate change as "a change of climate which is directly or indirectly attributed to anthropogenic activity, altering the global atmosphere's composition and contributing to natural climate variability over comparable time periods" (Pielke Jr 2004).

Historically, discussion of climate change dates back to the nineteenth century, when Greeks and Americans were worried about the impact of human activity on local climate, especially that of deforestation on rainfall in a specific region. However, the most significant climate changes have occurred naturally. In 1896, evidence emerged that fossil fuel combustion releases carbon dioxide, thereby contributing to global warming, although some critics minimized the human influence on extended climate cycles. By the 1930s, observations had confirmed significant warming in the United States and the North Atlantic region. During the 1950s and 1960s, when government funding increased, a number of scientific studies corroborated carbon dioxide accumulation in the atmosphere as a cause of global warming. In fact, while climate models predicted rising temperatures over the next century, there was no consensus on the need for immediate political actions. At the end of the 1970s, a resumption of global temperature increases was recorded, giving many climatologists the conviction that this trend would continue as greenhouse gases accumulated. Since 1988, experts have determined that without measures to reduce emissions, a doubling of carbon dioxide in the atmosphere would occur by the end of the twenty-first century, leading to a temperature increase of 2–3 °C at the Earth's surface. In 1990, the United Nations Framework Convention on Climate Change (UNFCCC) was adopted following recognition by the international community of the need for coordinated action, giving birth to annual Conferences of the Parties (COPs) designed to discuss climate-related issues. Then, in 1989, the Intergovernmental Panel on Climate change (IPCC) was created under the United Nations auspices to develop a scientific approach of climate change and the related political and economic outcomes. Two years later, IPCC reached a consensus emphasizing the significant risk of global warming. It stressed that future climate change primarily depended on the human policies chosen to manage greenhouse gas emissions. Scientific evidence of climate change has been strengthened, and the IPCC reports (2007) highlighting its effects on ecosystems, sea levels, extreme weather events and human societies (Agrawala 1998; Weart 2008; Sharma et al. 2012).

Causes and Future Projections

Anthropogenic Drivers of Climate Change

Climate change can be driven by both natural and human-induced (anthropogenic) factors that alter the radiation received from the Sun or emitted to space, or that modify the redistribution of energy within the atmosphere as well as between the atmosphere, land, and ocean (USEPA 2017). Human activities that contribute to climate change involve fossil fuel burning, deforestation, agricultural practices, urban expansion and pollutant emissions. These activities release greenhouse gases (GHGs) into the atmosphere, including but not limited to carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4), and water vapor (Meehl et al. 2007). These play a key role in climatic regulation. In fact, without GHGs the average temperature on Earth would be − 18 °C instead of + 14 °C and life might not exist (Omer 2008). However, GHGs from human activities are the main driver of climate change. Since the nineteenth century, humans have significantly increased the level of GHGs in the atmosphere. As a result, the natural climatic balance is being altered and the climate is being readjusted by a warming effect or positive climate forcing. In the period from 1990 to 2015, the worldwide net GHGs emissions generated by human activities had risen by 43% (Oreggioni et al. 2021). Additionally, carbon dioxide emissions accounting for about three-quarters of total emission, increased by 51% during the same period. Moreover, the total warming due to anthropogenic GHGs in Earth's atmosphere has increased by 45% from 1990 to 2019. The global warming effect attributed to carbon dioxide alone had increased by 36%. Population and economic factors are the main drivers of rising CO_2 emissions, with those from fossil fuel combustion and industrial processes accounting for around 78% of the total increase in greenhouse gas emissions (Oreggioni et al. 2021).

As for the global agri-food sector, more than 30% of global energy demand is primarily fulfilled by fossil fuel sources, leading to the emission of approximately 22% of total anthropogenic GHGs (FAO 2011). Burning fossil fuels, cement production, and other activities, elevate CO_2 levels, which reduce the CO_2 absorbed by trees. In addition, human activities related to farming using nitrogen fertilizers, raising livestock, paddy rice cultivation, landfill disposal and natural gas use, increase concentrations of nitrous oxide (N_2O) and methane (CH_4) in the atmosphere, making a substantial contribution to climate change (Fakana 2020).

Forests are well-known for their ability to absorb carbon dioxide from the atmosphere and convert it via photosynthesis into biomass, thereby acting as CO_2 sinks in a natural state (Fakana 2020). This process significantly contributes to the regulation of air and surface temperatures (Haghipour and Burg 2014; Güçlü 2014; IPCC 2019). The various forms of deforestation release the accumulated carbon dioxide stock into the atmosphere (Tahir et al. 2011; Ellison 2018). Periods of catastrophic rainfall followed by prolonged periods of drought have resulted from the disappearance of forest cover (Strasser et al. 2014).

Many other industrial and agricultural processes emit pollutants (other than GHGs) that generate aerosols including black carbon particles, which can induce either a warming or cooling effect (Melillo et al. 2014; Sims et al. 2015; IPCC 2019). Furthermore, fluorinated gases such as chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6), commonly employed in refrigerants, foaming agents, fire extinguishers, solvents, pesticides, and aerosol propellants, possess extended atmospheric lifetimes and impact the climate for several decades (Stocker et al. 2014).

Alongside the anthropogenic activities that are driving climate change, there are a number of major natural factors that influence the climate system, notably variability in solar intensity, volcanic activity, circulation of ocean currents, orbital changes (Milankovitch cycles), melting glaciers and rising sea levels, in addition to natural greenhouse gas emissions (Stocker et al. 2014).

Future Climate Scenarios

The climate modeling community has offered various time-dependent scenarios for climate change, forming the foundation for the majority of future projections in IPCC assessment reports. These standardized scenario sets have undergone evolution with each new generation, as the initial SA90 scenarios were replaced by the IS92 emissions scenarios of the 1990s, which were then succeeded by the Special Report on Emissions Scenarios (SRES) in 2000 and the Representative Concentration Pathways (RCP) in 2010 (Leggett et al. 1992; Nakicenovic et al. 2000; Moss et al. 2010).

The first scenarios namely; SA90, IS92 and SRES are all emission-based scenarios. They start with a set of assumptions based initially on demographic projections. In SRES, they are much more refined, providing a consistent pattern of demographics, international trade, information and technology flows, and other social, technological and economic characteristics of future worlds. Multiple integrated assessment models (IAMs) were used for the SRES, resulting in multiple emissions patterns corresponding to each scenario. However, one scenario for each scheme was chosen as representative "marker" scenario to be used as input to the global models in order to derive the resulting atmospheric concentrations, radiative forcing, and climate change. Thus, the following scenarios could be distinguished: A1FI (fossil fuel intensive), A2 (medium high), B2 (medium low), and B1 (low).

In contrast, RCPs, the most recent set of time-dependent scenarios, is the result of more than two decades of scenario development, and differ from previous standard scenario sets in at least four key respects. Firstly, RCPs are radiative forcing scenarios, and not emission scenarios. Radiative forcing quantifies the additional heat retained by the lower atmosphere due to the increased presence of greenhouse gases, measured in watts per square meter (W/m^2) (Jubb et al. 2013). Each RCP scenario is based on four distinct assumptions about the amount of greenhouse gases expected between 2000 and 2100, giving a likely climate variant related to the chosen emission levels considered as a working hypothesis. The four scenarios are assigned a number according to the change in radiative forcing by the year 2100 compared with pre-industrial levels: RCP 2.6 corresponds to a forcing of + 2.6 W/m^2, RCP 4.5 to + 4.5 W/m^2, and similarly for RCP 6 and RCP 8.5. A higher numerical value indicates a greater amount of energy gained by the Earth-atmosphere system, resulting in more significant warming (van Vuuren et al. 2011; Thomson et al. 2011; Masui et al. 2011; Riahi et al. 2011). The second difference lies in n the fact that, from these radiative forcing values, MAIs are applied in a reverse process to generate a spectrum of emission trajectories and their corresponding technology policies and strategies for each RCP that would have the same final impact on radiative forcing (Cubasch et al. 2013). Thirdly, the PCRs stand out from previous scenarios by incorporating explicit climate policies (for PCR 2.6, PCR 4.5 and PCR 6.0) to limit climate forcing. RCP 8.5 is a scenario in which CO_2 and CH_4 emissions persistently increase, despite a significant reduction in emission growth rates in the second half of the century. Atmospheric CO_2 levels in RCP 8.5 are projected to reach 936 ppm by the end of the century, surpassing 1200 ppm by 2100. Global temperature is projected to rise by 3–5.5 °C in 2100 compared to the 1986–2005 average. In contrast, the RCP 4.5 and

RCP 2.6 scenarios keep atmospheric CO_2 levels below 550 and 450 ppm by 2100 respectively (Collins et al. 2013; Melillo et al. 2014). Fourthly, a variety of socio-economic scenarios were developed independently of the RCPs. A subset of these scenarios has been constrained using emission limitation policies consistent with their underlying storylines, thus forming Shared Socio-Economic Pathways (SSPs) with climate forcing corresponding to RCP values. This combination of SSPs and RCPs is designed to meet the needs of communities responsible for impacts, adaptation and vulnerability (O'Neill et al. 2014).

As consequences, the environmental abiotic and biotic systems will increasingly degrade and the socio-economic component will undergo these transformations, which may cause the scarcity of resources, the upheaval of ecosystems or even crises and problems of insecurity.

Water Vulnerabilities in the Face of Climate Change: Issues and Impacts

Water is a primary natural resource crucial to sustaining life. It's evident that water has a vital abiotic role in maintaining the health of ecosystems and ensuring human survival on this planet, because of its importance to people's lives, agriculture and production processes (Bayart et al. 2010; Layani et al. 2021). Consequently, its crucial socio-economic influence profoundly shapes the well-being of human communities.

Many published investigations have revealed that all sectors of water, whether direct or otherwise, are experiencing the effects of climate change, in particular agriculture, hydropower, the economy, industry, tourism, biodiversity, food security, forestry, health, etc. This confirms the importance of considering water as a crucial aspect of adapting to climate change (Hall et al. 2015; Watts et al. 2015; Alhassan 2021; Wernberg et al. 2016; Zhang et al. 2017; Manes et al. 2021; Abbass et al. 2022).

Given that the repercussions of climate change are mainly water-related phenomena, notably changes in the severity and occurrence of extreme weather events, water will be a key factor in adapting to climate change. In fact, such impacts can be classified into three main categories: water insufficiency (droughts and water shortages), water excess (floods) and contaminated water (pollution) (Wehrey et al. 2023).

In terms of water-related disasters, floods are ranked the most frequent, accounting for 47% of all weather catastrophes, affecting 2.3 billion people worldwide. Meanwhile, storms, although occurring less frequently than floods, were responsible for over 242,000 deaths in the last 21 years, thus being rated the most fatal of all sever weather-related events. Furthermore, even though low-income countries experience only 26% of these natural disasters, an estimated 89% of storm-related fatalities occur within this group of nations (UNISDR 2015; Bhatt et al. 2020).

In addition to these meteorological disasters, there are waves of extreme temperatures, mainly heatwaves, which have been particularly deadly (with an average of 405 deaths per disaster). High-income countries rank second, behind lower-middle-income countries, in terms of the average number of victims per disaster (UNISDR 2015).

On the other hand, climate change-induced warming results in more intense, widespread and persistent extreme weather events, such as droughts (Meehl et al. 2007; Trenberth 2011; Mukherjee et al. 2018).

Climate change is expected to further exacerbate the pressures on available water resources posed by population growth, economic drivers and land-use changes. In fact, water reserves, particularly run-off, are projected to decrease by 10–30% in certain dry regions as a result of lower precipitation and higher evapotranspiration rates. It is also highly plausible that climate change will significantly reduce water resources in all semi-arid zones. Such variations in water availability, driven by climate change, would certainly have adverse consequences for many sectors, including agriculture, water supply, energy production and health (Raneesh 2014).

Water scarcity is complicated by the deterioration of water quality. Indeed, 2 million tons of wastewater as well as industrial and agricultural waste are discharged into waterways. A high portion of this wastewater is released untreated into surface waters (particularly in developing countries), resulting in more than 2 million deaths annually from diarrheal diseases. Additionally, the World Health Organization (WHO) reports that over 80% of all diseases are waterborne (WHO 2014).

Taken together, these data emphasize the key role of water as a multi-purpose resource for human security, environmental sustainability and sustainable development.

Climate Change in Morocco

Geographic Location and Climate Characteristics

Morocco lies in the north-western part of the African continent, surrounded by the Atlantic Ocean to the west and the Mediterranean Sea to the north. Morocco's climate varies widely among regions, as it is influenced by the Atlantic Ocean and plains to the west, the Mediterranean Sea and the Rif Mountains to the north, the Atlas Mountains in the central region, plateaus to the east, and the Sahara Desert to the south and southeast. Consequently, Morocco's climate is heavily shaped by its topography. In fact, most of the country, especially along the coast, is subject to the typical Mediterranean climate, marked by mild, wet winters and hot, dry summers. The northern Mediterranean coastal regions and the southern inland areas are geographically separated in the center by the Atlas Mountains, constituting a natural boundary (USAID 2016; Clement et al. 2021; World Bank Group 2021).

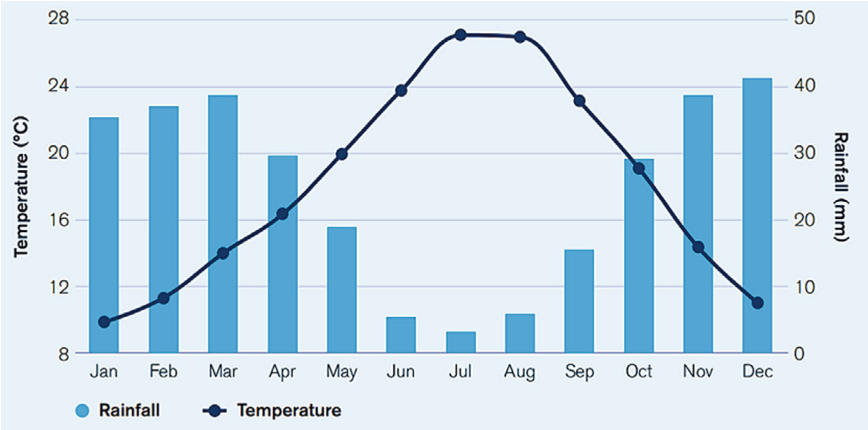

Fig. 1.1 Average monthly temperature and rainfall for Morocco, 1991–2020 (World Bank Group 2021)

The average annual temperature in Morocco is around 17.5 °C, with monthly fluctuations ranging from 9.4 (December, January) to 26 °C (July, August) (Fig. 1.1). However, there is considerable seasonal and regional variability. Temperatures along the coast vary from 18 to 28 °C in summer, and from 8 to 17 °C in winter. Inland, they can reach up to 35 °C in summer and drop below 0 °C in inland mountain areas. The southern zone is much more arid, recording an average annual precipitation of 100 mm. Whereas nationwide, the average annual precipitation is 318.8 mm, with the rainy season extending from November to March, and extremely low precipitation between June and August (Fig. 1.1). The influence of extratropical weather conditions originating from Europe and the Atlantic Ocean introduces cooler air, resulting in a reduction in the rainfall gradient from the northern to the southern part of the country, a phenomenon also influenced by the presence of the Atlas Mountains (Verner et al. 2018; Clement et al. 2021).

Climate Forecasts and Trends in Morocco

Morocco is recognized as one of the main hotspots of climate change due to the acceleration of global warming, notably because of the increase in average temperatures and decrease in precipitation levels in recent decades. Additionally, the country experiences noteworthy inter-annual seasonal variations and shifts in precipitation patterns.

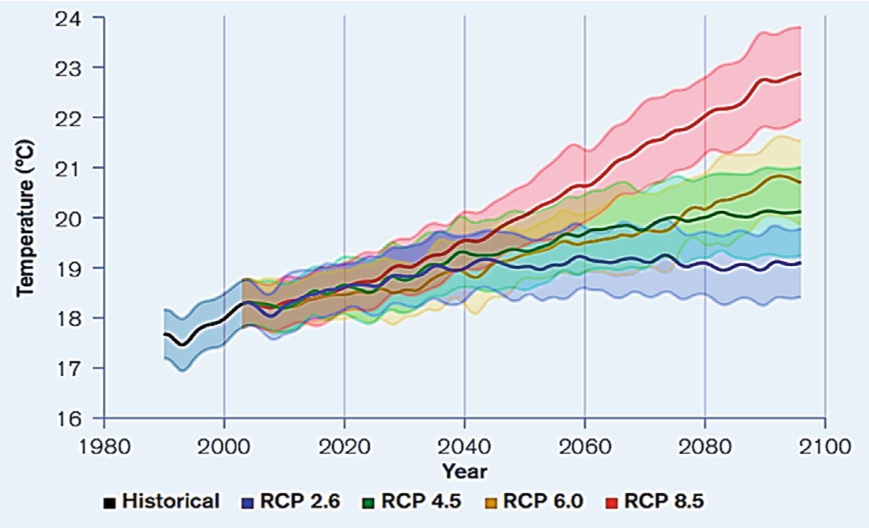

Fig. 1.2 Projected average temperature for Morocco (reference period, 1986–2005) (World Bank Group 2021)

Future Temperature Projections

Temperatures are expected to continue to rise throughout the North African region according to all emission scenarios. Increase of the average annual temperatures is projected to range within 1.5 and 3.5 °C of the mid-century horizon, and to exceed 5 °C by the end of the century (Fig. 1.2). Inland areas are expected to experience heightened warming, particularly with an anticipated increase in the frequency of "hot days" and "hot nights" (Fig. 1.3). The most substantial rise is projected to occur during the months of July, August, and September. Concurrently, there is a forecasted decrease in the occurrence of "cold days" and "cold nights," with their prevalence expected to dwindle to approximately 4% of days and nights by the end of the century (McSweeney et al. 2012).

Rising temperatures are also projected to reduce snow cover in the Atlas Mountains, leading to a reduction in the country's water supply and storage. Heat augmentation and extreme heat conditions will significantly affect human and animal health, agriculture, ecosystems as well as energy production.

Future Precipitation Projections

Precipitation projections for Morocco are widely divergent; however, scenarios forecast a substantial decrease in average annual precipitation throughout the entire country, varying from 10–20 to a 30% reduction in the Saharan region. According to the predictions, the reduction in water resources in Morocco will be due to an