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REVIEW

Morocco's climate change impacts, adaptation and mitigation—a stocktake

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Abstract

There are calls for effective measures to address climate change challenges for socio-economic development. This is a critical review to take stock of the impacts of climate change, and some gains made by Morocco in adapting to and mitigating climate change. This also highlights the challenges and opportunities of addressing climate change. A review is undertaken for peer-reviewed and grey literature published between 1951 and early 2022, mainly focusing on the main climate-sensitive sectors: water, energy and agriculture. Literature shows that climate change threatens food security, especially among small-scale farmers in Morocco. Insurance schemes against drought and tree crops are meant to build the resilience of agriculture against climate extremes. The water sector has prioritized the desalination of seawater and the national water saving program to cope with water shortages. The country has enforced its national environmental and sustainable development policy to support its target of reducing greenhouse gas (GHG) emissions by 45.5% by 2030. Massive investment in wind energy and decarbonization of the transport sector by promoting rail networks are outstanding initiatives in the energy sector. The country's involvement in environmental diplomacy exemplifies its local, regional and international efforts in environmental conservation. However, there are still issues, such as mainstreaming gender and youth in development activities. Other developing nations can take up Morocco's outstanding stories in concerted efforts to address climate change.

Keywords Water · Drought · Agriculture · Climate action · Renewable energy · Morocco

Introduction

Climate change is a threat to socio-economic development. The changing climate is partly driven by anthropogenic activities responsible for the observed increase in the concentration of atmospheric greenhouse gases (GHGs) (Hegerl et al. 2007). The situation has been projected to worsen, manifesting in the form of increased intensity and frequency of extreme events, changes in the water cycle and melting snow and glaciers (IPCC 2021). The impacts do not only threaten the realization of the United Nations Sustainable Development Goals (SDGs) globally (Mugambiwa and Tirivangasi 2017; IPCC 2018; Soergel et al. 2021) but are also likely to wipe out the gains made under the Millennium Development Goals, especially in developing countries.

The economies of many countries in Africa that rely mainly on rainfed agriculture are adversely affected by climate change, rendering them particularly vulnerable to its effects (IPCC 2019; Trisos et al. 2022). In Morocco, the agricultural sector is probably the most susceptible

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due to its high dependence on precipitation (Schilling et al. 2020). As per rainfed agriculture, crop productivity and land suitability for agriculture are expected to decrease under most climate change scenarios (Gommes et al. 2009). In an agropastoral basin in the northwest of Morocco where rainfed farming dominates, Brouziyne et al. (2018) projected a 40% decline in the productivity of major rainfed crops by the year 2050 due to changes in the mid-century climate pattern. Morocco's water scarcity and drylands environment are worsened by climate change projected to persist both in the medium to long term (Schilling et al. 2012; Choukri et al. 2020; IPCC 2021). This calls for effective adaptation measures to cope with both the observed and projected impacts.

In line with the Paris Agreement, many initiatives and commitments have been put in place from global to community levels to address climate change. Morocco is addressing its vulnerability to climate change by initiating adaptation and mitigation measures that contribute to global climate action despite its low emissions. These measures mainly concern the country's agriculture, forestry, water, energy and health sectors (Moroccan Government 2016). According to the 2022 Climate Change Performance Index (CCPI), Morocco scores 71.6% among the top climate change performers globally, behind Denmark at 76.67%, Sweden at 74.22%, Norway at 73.29%, and the UK at 73.09% (German Watch 2021: https://ccpi.org/country/mar/). The new African-specific Climate Change Policy Performance Index, based on GHG emissions, renewable energies, climate policy and corruption, ranks Morocco as number one in terms of its climate stewardship (Epule et al. 2021). The country performs exceptionally well in GHG emissions, energy efficiency and climate policy (German Watch 2021). This is commendable, exemplifying Morocco's leadership and investment of resources towards the realization of the country's unconditional target regarding GHG emission reduction of 18.3% below business as usual by 2030 and 42% to 45.5% for the conditional target (Climate Action Tracker 2021).

Many nations not only in Africa but across the globe are responding to the observed and projected climate changes in an effort to minimize the associated impacts. Thus, there is a need for reliable information for decision-making in the choice of practical and effective climate adaption and mitigate strategies. This review focuses on impacts of climate change, and the efforts made by Morocco in address climate change and conserving the environment at large. The knowledge gathered from this case study is important especially to decision-makers as it provides insights into the successes, failures, challenges and opportunities for initiatives especially in developing countries.

Study area and methodology

Methodology

Morocco has diverse climatic conditions ranging from sub-humid in the northwest to arid to desert conditions in the south. The agricultural sector, including forestry and fishery activities, employs nearly a quarter of the country's population, the majority of which are traditional subsistence farming, mainly rainfed (Ghanem 2015; Lopez-Acevedo et al. 2021; Meddi and Eslamian 2021). The sector accounts for about 12 to 18% of the Gross Domestic Product, with high year-to-year fluctuation depending on precipitation in the growing season (Meddi and Eslamian 2021).

This review considers a vast pool of scholarly peer-reviewed and grey literature on climate change adaptation and mitigation in Morocco. The review approach follows the proposal made by Pullin and Stewart (2006). The choice of the database is made by applying a search in the Web of Science, being the most complete database of scientific publications. The key terms included are 'climate change in Morocco', 'disaster risk reduction in Morocco', 'renewable energy in Morocco' and 'climate-smart agriculture in Morocco'. A search based on terminologies of interest such as 'leadership in Morocco' and 'education in Morocco', produced results that are a subset of 'climate change in Morocco'. The considered publication period is set to 1951–2022, as of March 1, 2022. The study period that is mainly characterized by increasing GHGs that consequently increased global temperature succeeded the Early Twentieth Century Warming (Voosen 2019).

Articles published in either English or French were considered in this study. French was considered since it is the widely used language in Morocco, thus, the approach factors articles featuring in national or regional journals. Although the main focus was on peer-reviewed articles, editorials, conference proceedings, book chapters and reports from credible institutions were included in the research.

Duplicates were identified based on the title and were removed. The abstracts were reviewed and those with a weak connection to the topic were excluded. All incomplete articles were excluded from the review. Table 1 gives the article selection and exclusion criteria, while Fig. 1 presents a summary of the review article selection process.

Findings

Understanding the past, current and projected climate change is important in devising effective adaptation and mitigation measures. This section presents findings on

Table 1 Summary of the inclusion and exclusion criteria of the articles reviewed

Inclusion	Exclusion
1. Published between 1951 and 2022	1. Published before 1951
2.Focusing on Morocco	2. Focusing on other parts of the Africa/world
3. Written in English and French	3. Non-English or French articles
4. Covering impacts of climate change, adaptation and mitigation	4. Covering adaptation metrics, climate model and data evaluation
5. Full article accessible	5.Incomplete article

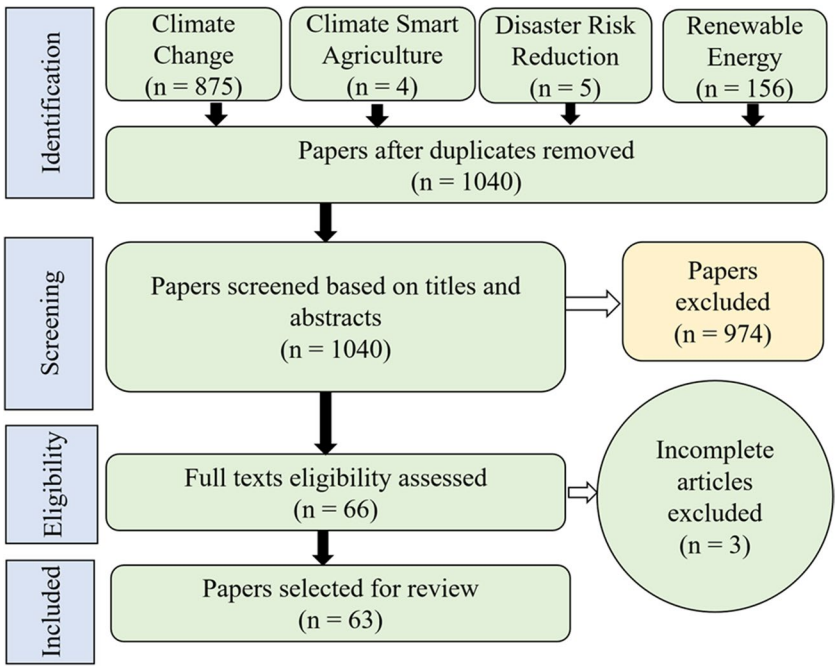

Fig. 1 The process summarizing selection of articles considered for review

climate change and associated impacts, and adaptation and mitigation efforts made in key sectors in Morocco. Table 2 presents a synthesis of the findings.

Climate variability and change and associated impacts

Like many parts of the world, Morocco is experiencing an increase in temperature (Khomsi et al. 2016; Filahi et al. 2016; Schilling et al. 2020; Driouech et al. 2021; IPCC 2021). Driouech et al. (2021) showed that the country warmed by approximately 1.1 °C between 1984 and 2016. This is consistent with the findings of Khomsi et al. (2015), who reported upward trends in both maximum and minimum temperatures in Morocco, with more significant changes in cold events than in warm events. Studies (e.g., Lelieveld et al. 2016; Fniguire et al. 2017; Zkhiri et al. 2019; Schilling et al. 2020; Meliho et al. 2020; Driouech et al. 2020; Elkouk et al. 2021) have reported an increase in droughts and heat waves in Morocco, as well as the entire Middle East and North Africa (MENA) region.

An increase in temperature and extreme weather and climate adversely affects important socio-economic sectors such as water and agriculture, as conceptualised in Fig. 2. Water scarcity in Morocco explains the sensitivity of the country's hydrological sector to climate change. Precipitation is on a downward trend nationally and regionally, with spring precipitation showing a reduction of over 40% since the 1960s (Meddi and Eslamian 2021). Regional studies show that north-eastern Morocco has recorded less precipitation since the mid-1970s than the long-term mean (Fink et al. 2010; Filahi et al. 2016; Abahous et al. 2018; Driouech et al. 2010, 2021).

The drought over the country is exacerbated by precipitation decline and is regarded as the top threat in the region (Karmaoui et al. 2019; Ouatiki et al. 2019). The precipitation trend leads to a reduction in groundwater recharge (Hssaisoune et al. 2020). The situation is even dire following the growing population, which increases water resources pressure (Malki et al. 2017). For instance, between 1980 and 2017, the Saiss plain aquifer greatly influenced the Meknes region and recorded a drop of 3 m/year in the piezometric

Table 2 A synthesis of the climate change, impacts, adaptation, and mitigation measures implemented in Morocco

	Indicators	Impacts	Adaptation		Mitigation	
Climate change	• Temperature increase 1.1 °C between 1984 and 2016 • Increase in maximum and minimum temperatures • Reduction in spring precipitation since 1960s	• Reduction in groundwater recharge • Reduced agricultural productivity • Sharp increase in climate related diseases • Heat waves and droughts	Agriculture	• Water conservation • Promoting tree crops • Agroforestry • Subsidized crop insurance • No-till Agriculture Support Project • Irrigation Modernization Project • Khettara Rehabilitation • Soil conservation • Drought-resistant varieties	Policies and legislation	• Leadership • Climate change treaties • COP22 • Articles 31, 35, and 88 of constitution • Law 77.15 • National Charter for Environment and Sustainable Development • National Strategy for Sustainable Development • Climate Change Policy • Competence Center for Climate Change • NDC
			Water	• Wastewater treatment • Reuse • Seawater desalination • National Irrigation Water Saving Program • Irrigation Extension Program • Rehabilitation and Safeguarding of the Small and Medium Hydraulic perimeters • Public-Private Partnership Promotion Program	Energy	• Low-carbon economy • Scrapping fossil fuel subsidies • Moroccan Solar Plan • Morocco Integrated Wind Energy Program • Improved energy efficiency in transport, residential, and industrial sectors • Green molecules
					Transport	• Switching to clean fuels in public transport • Promotion of transport by modernised railway network • Restriction of import of ageing cars • Renewal of taxi fleet • Setting up charging docks across major cities for electric cars • Implementing fiscal measures to encourage electric car market
					Climate Finance & Private Sector Investments in Climate Action	• Global Climate Funds • Climate Change Public Expenditure and Institutional Review • Moroccan Centre for Clean Manufacturing • Law No. 58-15
					Leadership	• Stable governance • Political goodwill
					Education and Public Awareness	• Public education programs • National Charter for the Environment and Sustainable Development • Mohammed VI Polytechnic University

level (Amraoui 2019). The reduction in aquifer level is associated with several devastating implications ranging from irrigation water deficit that ruins agriculture to poor water quality. Heidecke and Heckelei (2010) reported the likelihood of a reduction in the profitability of irrigated agriculture in Morocco because of increased groundwater pumping costs and the risk of aquifer salinization. In Moulouya River Basin, it is estimated that the per capita availability of blue water is below 500 m^3, which is the minimum threshold per year (Tekken and Kropp 2012). This shows how the ongoing water scarcity impacts the basin.

Climate change is exacerbating the strain on Morocco's fragile drylands and livelihoods that rely mainly on environmental-based resources. In agriculture, the productivity of wheat, which is one of the country's staple foods, accounting for about 75% of cereals, drops drastically during drought events (Jarlan et al. 2014; Bregaglio et al. 2015; Bishaw et al. 2019; Bouras et al. 2019, 2020). According to Bouras et al. (2019), if climate change-effective adaptation measures are not implemented, a reduction in wheat yields by 7 to 30% is expected by the end of the century in the Tensift region of Morocco.

The health sector is not spared from the effects of climate change. According to Kholoud et al. (2018), Morocco has recorded a sharp increase in the cases of cutaneous leishmaniases attributed to climate change, mainly warming. The changes have been extensively reported by Ait Kbaich et al. (2017) and Hakkour et al. (2020). Abdelkrim et al. (2021) identified the potential distribution and habitat suitability of Arboviruses vectors in the current and future climate conditions in Northern Morocco (Abdelkrim et al. 2021).

Adaptation

Climate change adaptation measures vary from sector to sector and, most notably, with the needs of a given community/country. This implies that the measures vary with time depending on the needs (Fig. 3). Mitigation and adaptation to climate change are cross-sectoral efforts that must include all the country's development sectors, such as agriculture, industry and tourism. Notably, adaptation and mitigation differ, particularly in their objectives (Fig. S1). Consequently, most initiatives specifically address climate change adaptation, mitigation or both. Table S1 gives a summary of climate fund projects in Morocco, addressing both adaptation and mitigation.

Agriculture

Most initiatives across Africa to build resilience to climate change mainly focus on agriculture and water, the most vulnerable sectors to climate change (Schilling et al. 2020; Williams et al. 2021). In Morocco, concerted efforts have been made to overcome the challenges, boost food production and conserve available water resources to meet growing demand. However, Schilling et al. (2012) noted that the agricultural incentives that Morocco is using are inadequate to buffer drought effects, especially for small-scale farmers. The study called for agricultural policies that maximize agricultural output, stabilize revenues and increase resilience to climate change. Similar findings were reported by Verner et al. (2018) that recommended for more to be done to share information and strengthen inter-governmental and interagency coordination, especially with governments at the river basin level. This is in addition to what the government is doing such as monitoring and crop insurance programs in an effort to promote climate resilience development (Fig. 4).

Morocco is promoting tree crops, mainly high-value tree orchards, in an effort to replace cereals to increase resilience to low and poorly distributed precipitation. However, the large-scale conversion of the dominant cereal cropping systems to agroforestry poses challenges since tree orchards consume much more water than annual crops. In northern Morocco, agroforestry practices are in place and have become integral to all farming systems (Kmoch et al. 2018). This practice has been embraced in the region despite its challenges, such as water scarcity, uncontrolled grazing and low profitability. On the other hand, there has been a decline of 11% in agricultural value added for cereals between the periods 2003–2005 and 2015–2019 (Government of Morocco 2020a, https://www.agriculture.gov.ma/en/node/59). The decrease is to the benefit of arboriculture and white meat, which have increased by 11% and 2%, respectively.

Many small-scale farmers depend on rainfed agriculture. In Morocco, the Ministries of Agriculture and Finance, in partnership with the *Mutuelle Marocaine d'Assurance Agricole* (MAMDA, the leading agricultural insurer in Morocco), provide climate-risk insurance coverage to cushion against climate-related losses (Verner et al. 2018). The insurance scheme covers small- and large-scale farmers against various risks. Although coverage for hail, fire and livestock insurance is voluntary, farmers must cover droughts. The government subsidizes the insurance under the Green Morocco Plan.

The Green Morocco Plan has been successful, although not as much as initially planned. For instance, out of 1.15 million jobs expected to be created by 2020, it is estimated that only 342,000 had been realized as of 2018. Recognizing the latest projections showing that the country is likely to get drier and hotter (IPCC 2021; Hadri et al. 2021), the Department of Agriculture has developed a new agricultural strategy, 'Green Generation 2020–2030' (Government of Morocco 2020b) to improve water efficiency through the continuation of irrigation control and agricultural land development programs, as well as the mobilization of

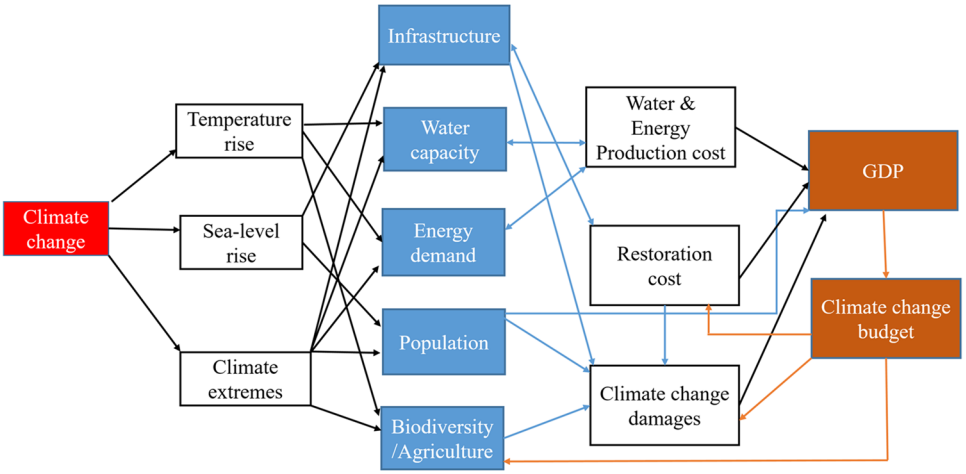

Fig. 2 Conceptual climate change impact pattern (modified from Moon et al. 2021)

non-conventional water resources, the dissemination of soil conservation techniques and continuation of the agricultural insurance program. However, under the Green Morocco Plan, an increase in irrigation water use was recorded because of increased irrigated surfaces boosted by government subsidies and the transformation of annual crops to much more profitable orchard trees. This trend will likely continue under the Green Generation 2020–2030, increasing water demand.

The Adaptation of African Agriculture initiative (AAA—https://www.aaainitiative.org/en/initiative) has projects aimed at reducing the vulnerability of Africa's agriculture to climate change in Morocco. Generally, its projects centre on improved soil management, climate risk management, agricultural water control, capacity building and financing solutions. The projects are divided into three categories: climate-resilient agriculture investment plan (CSAIP), Adaptation Metrics and the Pan African Readiness Program. In Morocco, the CSAIP includes three projects: (1) scaling-up of ongoing programs with a focus on resilience and/or mitigation, (2) new projects with a focus on resilience and/or mitigation, and (3) capacity-building projects. In the first category, projects being undertaken are the No-till Agriculture Support Project and the Irrigation Modernization Project, while in category 2, the Khettara Rehabilitation in the Draa-Tafilalet Oasis Region project, and the Massa Basin Soil and Water Conservation Project, are being implemented. The Rangeland Monitoring Pilot Project and the Agro-Meteorological Risk Management Project are ongoing projects under the Capacity Building category.

Another example is led by the Institut National de la Recherche Agronomique (INRA, the national institute for agronomic research in Morocco), which has been engaged for decades in developing drought-resistant varieties of wheat that are part of the 5 million hectares cropped with cereals every season (Jlibene 2011).

Water

The government is implementing measures to improve water efficiency and minimize resource waste. Besides improved efficiency irrigation initiatives touted to be critical to climate adaptation approaches in water-scarce regions, Morocco has invested a lot in wastewater treatment, reuse and seawater desalination. This is part of the country's National Water Plan (NPE), an aspirational action plan focusing on all aspects of the water sector through 2050. Other sub-sectors under NPE include water supply and distribution, dam engineering and construction, groundwater exploration and water transfer supply and distribution.

To save water, irrigation techniques and programs have been implemented. These are the National Irrigation Water Saving Program (PNEEI), Irrigation Extension Program (PEI) downstream of dams, Program for the Rehabilitation and Safeguarding of the Small and Medium Hydraulic (PMH) perimeters and Public-Private Partnership Promotion Program that develops new irrigation projects within the framework of public-private partnerships (Jobbins et al. 2015). Morocco's national agricultural strategy mainly focuses on controlling irrigation water, which uses approximately 80% of the country's surface water (MDCE 2016). Since adopting the Green Morocco Plan, more farmers have adopted water conservation measures such as high-efficiency drip irrigation. This goal was achieved by offering a 60% subsidy for the installation of drip irrigation, especially on farms > 5 ha (Berrada 2009). Following the adoption of the drip irrigation system, the Ait Ben Yacoub region of Morocco reported an improvement in gross farm margin (Elouadi et al. 2020). In the Gharb region of Morocco, while focusing on water use efficiency in drip irrigation of sugarcane, Aabad et al. (2017) estimated that drip irrigation could save half of the water consumed by sprinkler irrigation. Further, the study found increased sugar yields from 8 to 23 tons/ha under drip irrigation. Although the irrigation system is widespread, especially among large-scale

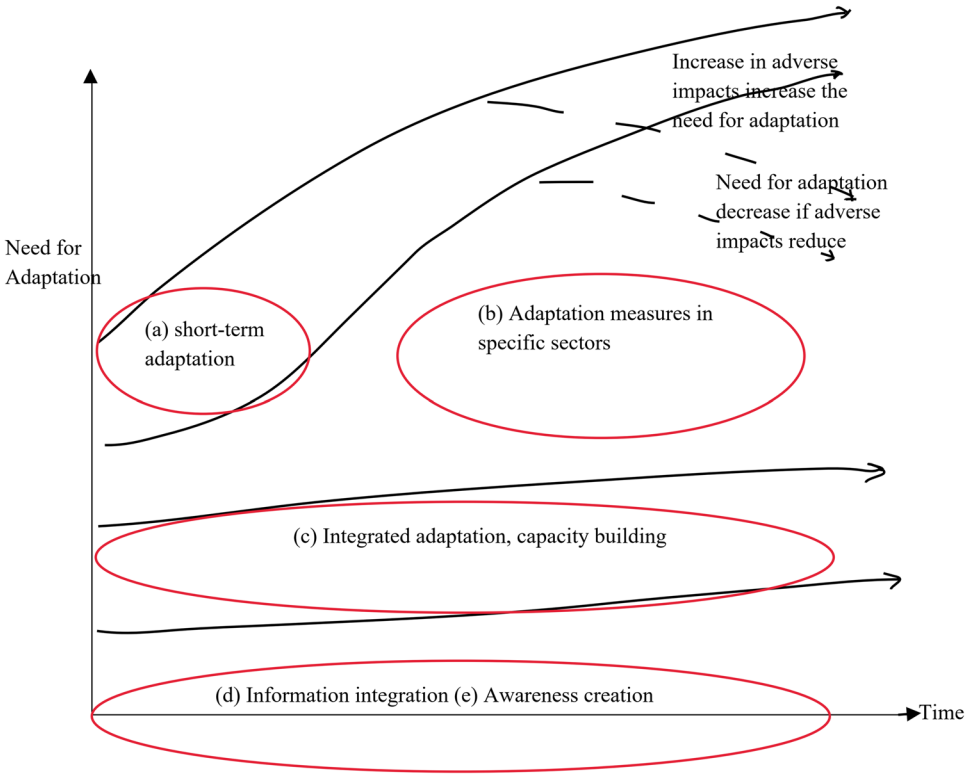

Fig. 3 Conceptual types of adaptation strategies required with time (modified from Mimura et al. (2010)

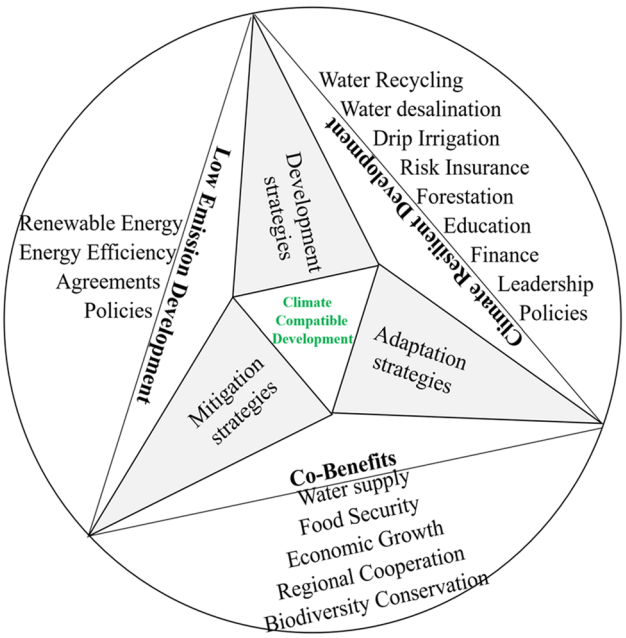

Fig. 4 A summary of climate change adaptation and mitigation measures employed by the Moroccan government and the associated benefits

tree crop farmers, there remains a need for more investment to accommodate small-scale farmers with financial limitations. In some cases, over-irrigation of crops has been observed, wiping away the desired intention of water conservation and cost reduction at the field level (Boularbah et al. 2019). Further, the program favored large-scale farmers, sidelining small-scale holder farmers mainly in rural territories (Faysse 2015). Such biases partly undermined the Green Morocco Plan's ability to achieve significant improvements at farm and territorial levels, widening economic inequality between the large- and small-scale farmers.

The seawater desalination plant of Chtouka in the Agadir area is one of the country's flagships in an effort to develop water supply. With a total cost of approximately MAD 4.48 billion ($478 million), this desalination station is to provide, during the first phase, 275,000 m^3/day, of which 125,000 m^3/day will be for irrigation water needs and 150,000 m^3 for the Agadir region drinking water needs. The long term target is to reach 400,000 m^3/day of desalinated water, shared equally between drinking water and irrigation water (Moroccan Ministry of Agriculture 2020). This project is expected to increase the adaptation of irrigated agriculture in the Chtouka plain to the uneven supply of irrigation water due to climate change-induced water scarcity in the region and the high costs of groundwater extraction due to the drop in the water table. Other desalinization plants are in progress in Casablanca, Safi, Tan Tan and Dakhla, which will increase water availability for drinking and agriculture.

Mitigation

The Paris Agreement, reached at COP21 in Paris in 2015, resolved to limit the rise in the global average temperature

to 1.5 °C. Despite the submission of new or updated Nationally Determined Contributions (NDCs) by 151 Parties before COP26, there is still a gap between national policy ambitions and the required commitment if the increase in global temperature is to stay below 1.5 °C (UNEP 2021b). Morocco has identified and experimented with various projects aimed at mitigating climate change. On the CCPI 2022, Morocco ranks 8th out of 60 (Climate Action Tracker 2021). Specifically, the country performs very well on the GHG 2030 target, emerging 4th globally. The country's rating is likely to go up due to its concerted mitigation targets for two new major industrial sub-sectors: cement and phosphates. In its updated NDCs, the country targets a 45.5% reduction in GHG emissions by 2030. Of this target, 18.3% is unconditional, and the remainder is conditional upon international assistance (Climate Action Tracker 2021).

The objectives of sustainability in the use and management of natural resources and the environment, and climate change action, have been consolidated and anchored in public management with the advent of the 'new development model' (NDM) (Government of Morocco 2021). This roadmap has just been adopted by the country's highest authorities and outlines the country's development objectives by 2035.

Policies and legislation

Morocco's commitments and leadership in climate change affairs in Africa and globally are evident through its participation in formulating, committing and implementing international climate change treaties. In the spirit of cooperation to promote environmental conservation, Guaadaoui et al. (2021) note that Morocco remains interested in sharing its lessons learned with other countries, especially developing ones.

Morocco is one of the countries that adopted the United Nations Framework Convention on Climate Change (UNFCCC) in 1992 at the Rio Summit. The ratification of the relevant international conventions and adoption of national action programs at the summit was meant to stimulate global sustainable development. This was followed by numerous conventions to which Morocco is a party. Under the Paris Agreement, the Moroccan government has committed to reducing GHG emissions by 17% from the business-as-usual scenario by 2030.

Since 1992, Morocco has engaged in international climate negotiations. It hosted COP7 in 2001 and COP22 in 2016. Morocco is a member of several negotiation groups within the global climate negotiations system: the African group, the Arab group and the G77. The hosting of the UNFCCC's COP22 in 2016 in Marrakech affirmed Morocco's commitment and global leadership role in climate change action. The event brought together various environmental and leadership stakeholders from around the world to discuss the implementation of the Paris Climate Change Agreement. The conference, among other issues, marked illustrious actions towards fusing water within climate policy. The COP22 gave birth to the AAA initiative. To date, the AAA has supported over 23 African countries to secure $7 million from the GCF for the Pan-African Readiness Program (https://www.aaainitiative.org/en/projets#plan_investissement). The program implements low-carbon and climate resilience strategies in the agriculture and energy sectors. In connection with COP22, a memorandum for creating the Blue Fund was inked at the same conference. One of three regional initiatives of the fund is the Congo Basin Blue Fund (https://www.ccbc-cbcc.org/). The initiative is seeking funds to support the implementation of projects that promote sustainable development and the blue economy in the basin.

Morocco's new constitution of 2011 gives its citizens the right to water and a healthy environment in Articles 31, 35 and 88 (Royaume du Maroc 2011a, http://www.sgg.gov.ma/Portals/0/constitution/constitution_2011_Fr.pdf). The government has put in place initiatives to help fulfil the commitment to its citizens. Some of these programs are the National Sanitation and Wastewater Treatment, Prevention of and Fight against Industrial Pollution, National Municipal Solid Waste Management and Environmental Upgrading of Rural Schools (GIZ 2014; Llorent-Bedmar 2014; Belloulid et al. 2018; Diaco et al. 2020). Other than the constitution, the country's parliament, in July 2016, signed a bill into Law 77.15, banning the production, importation and exportation, or use of plastic bags throughout the country. Further, enacting the framework law on the National Charter for Environment and Sustainable Development (CNEDD) in 2012 and developing a National Strategy for Sustainable Development (SNDD) in 2015 represents the distinct stages in Morocco's engagement in the fight against climate change.

Morocco elaborated its first National Plan against Global Warming (PNRC) in 2009, which was presented to COP15 in Copenhagen. This plan contains a portfolio of actions and detailed programs for mitigation and adaptation. It is the first attempt to address the need for an integrated approach with the coordination of sectoral policies.

The Morocco Climate Change Policy (PCCM), developed in 2013, poses the main principles, defines global strategic priorities for mitigation and adaptation and systematically traces the sectoral actions to address climate change by different sectors in Morocco. The PCCM established a time horizon until 2030 with specific deadlines and goals for most sectoral and inter-sectoral national strategies and aims to be a dynamic and flexible instrument with a monitoring and evaluation mechanism that allows for the necessary refinements. The Competence Center for Climate Change (4C Morocco) was established in 2016 to institutionalize and formalize the structures for Morocco's climate policy.

In its NDC, Morocco presents a list of 55 mitigation actions for 2030 to achieve the conditional and unconditional

GHG emission reduction targets. The portfolio includes activities in all sectors of the economy. However, the most significant reductions are related to the transition of Morocco's energy sector. The National Energy Strategy is critical for implementing Morocco's mitigation contributions.

Nationally, Morocco has made several efforts to comply with its commitments by setting up the institutional framework for developing a national policy of adaptation and mitigation of climate change effects. In addition, the legal arsenal has been strengthened. Table S2 summarizes the most important legislation in the country regarding climate change mitigation, pledges to cut GHG emissions and adaptation.

Energy

Energy is known to drive nearly every sector of the economy. For a long time, approximately 70% of Morocco's energy depended on hydrocarbons, burning fossil fuels (Nfaoui and Sayigh 2013), 96% of which is imported (Richts 2012).

Following massive investment in the sector, the country's renewable energy potential gives optimistic expectations to create a sustained low-carbon economy (Kousksou et al. 2015). It still has high renewable energy resources, mainly solar and wind power, which are still under-utilised (IEA 2014). The country is making commendable efforts towards achieving SDG7 by ensuring access to affordable, reliable, sustainable and modern energy. According to World Bank (World Bank Open Data 2019), most of Morocco's population, especially in urban centres, has access to electricity compared to only 44.6% of the population in Sub-Saharan Africa. Morocco is working on an ambitious energy transition path that is investment intensive, calling for both the private and public sectors' investments to achieve its renewable energy and energy efficiency targets (Schinko et al. 2019). In a show of determination to this course, Morocco has done away with fossil fuel subsidies. Such policies have helped promote sustainable energy practices.

Morocco is utilizing its resources, both natural and human, to achieve its NDCs. Policies and initiatives mainly revolve around renewable energy resources and are intended to decarbonize and stimulate socio-economic growth through sustainable job creation (Choukri et al. 2017). Two critical projects under the National Energy Strategy aiming at reducing emissions of GHGs are the Moroccan Solar Plan and the Morocco Integrated Wind Energy Program. The country has committed and is striving hard to exceed 50% sustainable energy reliant by the year 2030 and achieve 100% renewable energy by 2050.

In 2019, the country presented its 2030 Climate Action Plan. The plan's objectives affirm those of the NDC and the National Energy Strategy. The program has a different governance structure, the National Committee for Climate Change, which implements and coordinates climate policy.

Morocco has significant solar energy owing to its relatively high solar radiation with an average of 5.3 kW h/m^2 (Ouammi et al. 2012; Kousksou et al. 2015; Tazi et al. 2018; Azeroual et al. 2018; ONEE 2019). Key projects include Ouarzazate's Noor Solar Power Plant (NOOR I, II and III). These solar farms are the largest in the world, supporting close to one million people, saving nearly one million tons of oil and cutting carbon emissions by 3.7 million tons of CO_2 per year (KfW 2017). Both domestic and international green bonds mainly financed the Ouarzazate Solar Power Station by various funding agencies, including the World Bank and the African Development Bank. Preliminary studies show that the project has brought multiple benefits, such as improving the agriculture and economy of the region, including enhancing the palm grove in the Ghessate village (Laaroussi et al. 2021).

Besides solar, Morocco is endowed with a high wind power potential (Enzili et al. 1998; Hochberg 2016; Azeroual et al. 2018; ONEE 2019; El Khchine et al. 2019; Benazzouz et al. 2021). Statistics show that offshore wind power potential is higher than inland (ONEE 2019; Benazzouz et al. 2021). Today, the country has operational and in-construction wind power plants, with the Tarfaya plant, commissioned in 2014, having the largest capacity of 301 MW (Kousksou et al. 2015). In some sites, old wind turbines are being replaced with more powerful ones. The development and usage of this power is guided by the country's national energy strategy launched in 2009. According to Haidi et al. (2021), Morocco has realized 80% of the first step of its integrated wind energy program, which is aimed at having wind energy constitute 14% of the total energy production and renewable energies representing 42% of its energy mix.

As part of a strategy to promote investment in and use of clean energy, Morocco is reducing public subsidies on fossil fuels. Haidi et al. (2021) appreciate the role played by local companies in the design and manufacturing of wind turbine parts, such as towers and blades, to support the installation, production and supply of wind power across the country. Further, government policies have provisions for private renewable energy suppliers to integrate their energy into existing energy grids (Hochberg 2016).

On top of energy generation, the Moroccan government, in collaboration with various sponsors, has embarked on improving energy efficiency in the transport, residential and industrial sectors to cut down GHG emissions (Hamdaoui et al. 2018; El Iysaouy et al. 2019). The initiatives to realize this is governed by Law No. 47-09 on the energy efficiency of November 17, 2011 (Royaume du Maroc 2011b). One such project is the integrated planning and energy efficiency to increase the use of climate technologies (2017–2020), commissioned by the German Federal

Ministry for Economic Cooperation and Development (GIZ 2019). The project, among other strategies, developed a market for energy efficiency and supported developing application-oriented research and designing a test platform for energy-efficient buildings. The project promoted energy efficiency in Morocco by introducing an Energy Management System (EMS) that aligns with national contributions towards climate goals.

From another perspective, Morocco has initiated a regional dynamic which aims to create an economic and industrial sector around green molecules, mainly hydrogen, to consolidate its energy transition by contributing to the reduction of GHG emissions and supporting the decarbonization of partner countries. The establishment of the green hydrogen industry and its derivatives, 'Power-to-X (PtX)', should enable Morocco to diversify its energy mix by integrating renewable energy sources in sectors difficult to decarbonize. Establishing a domestic hydrogen-based industry would first replace ammonia imports with local production of this important feedstock for the fertiliser sector. This transition will de-risk this vital activity for the country and guarantee a long-term supply (Moroccan Ministry of Mines and Environment 2021).

Transport

The transport sector is one of the leading contributors to climate change through GHG emissions, contributing approximately a quarter of total global emissions (Creutzig et al. 2015; Lamb et al. 2021). In Morocco, as in other developing countries, the sprawl of towns makes it challenging to decarbonize the transport sector, which is the leading sector in total final consumption (KIFAL 2020). The country is switching to clean fuels to reduce emissions of GHGs and is improving its existing public transport networks. Today, it is estimated that more than 60% of the country's rail network runs on electricity (ITF 2021).

Among the actions undertaken by the government to reduce the carbon footprint of Morocco's transportation sector are the promotion of transport by modernized railway network and solar-powered bus in major cities, restricting the import of ageing cars, renewing the taxi fleet across Morocco and developing the electric car segment by setting up charging docks across major cities and implementing fiscal measures to encourage electric car market (Ministère Délégué auprès du Ministre de l'Energie, des Mines, de l'Eau et de l'Environnement Chargé de l'Environnement 2016).

Kharbach and Chfadi (2017) investigated the energy consumption by the transportation sector of Morocco. Their results provide evidence relative to the Environmental Kuznets Curve hypothesis, which shows that Morocco's economic growth will lead to a reduction in CO_2 emissions. They also showed that the trend can be reinforced and accelerated by promoting public transportation and implementing other 'demand side' initiatives.

Climate finance and private sector investments in climate action

Morocco benefited from global climate funds dedicated to helping countries implement their adaptation and mitigation strategies. The support provided by dedicated multilateral and bilateral climate funds to Morocco in 2017 shows that about USD 800 million was approved for Morocco in the form of concessional loans, while grants are almost negligible, making Morocco one of the most supported countries of climate finance after India and Brazil (Driss and Naima 2019). Nevertheless, international support for Morocco's adaptation efforts remains weak as most of these funds (about 95%) are attributed to mitigation projects, while only 4% support adaptation projects.

In 2012, the World Bank, at the request of the government of Morocco, conducted a thorough Climate Change Public Expenditure and Institutional Review (CCPEIR) by looking at Morocco's public expenditures from 2005 to 2010. Morocco was one of the first developing countries to undergo such a review (World Bank 2012). Five sectors were selected based on their mitigation potential and climate vulnerability: agriculture, energy, water, forestry and waste management. The CCPEIR assessed how well climate spending was mainstreamed in the national budget process and looked at the country's climate governance arrangements. The CCPEIR found significant public investments by the government of Morocco in the selected five sectors, mainly in infrastructure programs and with a focus on adaptation-related water resources management.

Morocco has adopted a market-based approach to development and seeks to promote private-sector growth. The General Confederation of Moroccan Companies (CGEM) is taking the lead in coordinating domestic private sector investments in climate action through the Moroccan Centre for Clean Manufacturing (CMPP, https://www.usinenouvelle.com/article/industrie-comment-produire-plus-propre-au-maroc.N202122). The CMPP promotes the adoption of green technologies and production processes and is seeking to support the development of green industries in Morocco.

In late 2015, the government of Morocco adopted Law No. 58-15 (Table S2) as a complement to Law No. 13-09 by amending the renewable energy law and introducing a net-metering scheme for solar panels and onshore wind plants, initially only for power plants connected to the high-voltage grid. Those connected to the middle- and low-voltage levels will also be eligible later. Private producers may sell up to 20% of their production to the grid.

Leadership

The role of leadership is one of the most important factors in mainstreaming climate change adaptation into development (Mogelgaard et al. 2018). However, it has been understudied in climate change adaptation and mitigation (Moser 2010) implying that a lot of emphasis has not been placed on it. In climate change affairs, all leadership functions are necessary for political administration and to provide an enabling environment, connections and dissemination of information. Morocco has stable governance that has allowed the country to achieve steady economic growth over recent years (World Bank 2020a). Furthermore, all of Morocco's strategic plans and programs related to climate action and sustainability benefit from the immediate care of his Majesty the king of Morocco, which reflects the supreme commitment of the country to climate and sustainable development agenda.

Education and public awareness

Education is essential not only for environmental conservation but also for driving a change in society. As a result, Morocco has clearly defined the need for public education programs, academic learning institutions and training for the Moroccan people in the country's National Charter for the Environment and Sustainable Development (http://www.chartenvironnement.ma/). For example, the Mohammed VI Polytechnic University (https://www.um6p.ma/) prioritizes African climate education. The university currently hosts the African Youth Climate Hub incubator for green startups.

Discussion

Like many other developing countries, Morocco invests in industrial and agricultural growth. However, it is challenged by its population growth, desertification and climate change (Mirzabaev et al. 2019). The country is arguably at the frontline of environmental conservation. Its efforts and initiatives to address climate change and preserve the environment are supported by policies mainly centered on public awareness and education, water conservation, energy efficiency and renewable energy production (Fig. 4). The projects in the water sector focus on water treatment, groundwater replenishment, dam construction and desalination.

Like Morocco, most African countries are endowed with renewable energy resources, mainly solar, wind and hydropower. These renewable energy resources need to be assessed and harnessed to meet the growing energy demand while meeting the objectives of the Paris Agreement. Morocco has invested in renewable energy to optimize the synergy and the gains of its energy projects as it aims at helping handle Africa's energy challenge for sustainable economic development and environmental protection. In this regard, Morocco is a suitable model for other developing countries to follow.

Despite Morocco's ambitious climate strategy, potential challenges continue to limit the achievement of set objectives. On the one hand, Morocco currently has a very low GHG emission rate, which is anticipated to increase significantly in the coming decades during the country's continuing economic development (Climate Action Tracker 2021). To limit the GHG emission increase, the country will need substantial financial investment in green technologies in various socio-economic sectors. On the other hand, Morocco is currently highly dependent on fossil fuel imports. Especially, the continuing relevance of coal to meet the country's primary energy demand and the strategy to expand natural gas use could become critical (IEA 2018).

The country signed up to international climate and environmental commitments, including the Paris Agreement. However, there remains a need for increased stakeholder participation (public, scientific institutions, women and local communities) in the planning and managing of environmental affairs at the national level (Climate Risk Profile: Morocco 2021). Notably, despite the country's sectorial climate change adaptation mainstreaming, there is a need for an integrated approach to address climate change in the country (Tudose et al. 2021). This will help to break the 'silo approach' to decision-making and project implementation that, thus, promote the realization of cross-sectoral and cross-scale harmonization. This move calls for a dedicated leadership to spur further multisector collaborations.

In an effort to promote climate resilience across the country, there is a need to address economic inequality and social inclusion, with focus on mainstreaming gender and youth in the developments. According to World Bank (2020b), poverty rates in rural areas doubles those at the national level. Unfortunately, the rural areas are mainly occupied by women and the elderly, who are more vulnerable to effects of climate change. The recent efforts, such as the integration of gender mainstreaming into programming and budget planning (Lakchiri et al. 2022), are in the right direction but more is yet to be done.

The barriers to climate change adaptation and mitigation initiatives in most developing countries, especially in Africa, are mainly finance, data availability and quality, policy and governance systems (Sibiya et al. 2023; Kweyu et al. 2023). However, there are several climate finance streams that have been made available through various established research funds, green bonds and donations. The access and good utilization of these funds requires a good governance system that is equally a challenge to many African countries. According to Kweyu et al. (2023), this is a challenge for African countries to promote good governance and diversify their economies to tackle climate change, tapping into the resources

they are endowed with renewable (e.g., water, solar energy, forest) and depletable (e.g., minerals, oil).

Data quality and availability are key in promoting climate-related research for informed decision-making. Unfortunately, the quality of station datasets is low partly owing to low observation network, and the available data is not easily accessible (Dinku 2019). According to Baninla et al. (2022), most African institutions lack adequate research, which limits efforts to address climate change across the continent. According to Kaspar et al. (2022), some historical hand-written weather observations exist in different countries across the continent and require digitization to be useful. In general, data observations in Africa require more investments and, most importantly, agreements for free data sharing as well as sharing of best climate adaptation and mitigation practices.

Addressing the constraints of climate change adaptation and mitigation will not only help build the continent's resilience to climate change but also promote socio-economic development by providing a range of other benefits. For instance, prioritizing nature-based solutions that synergize adaptation and mitigation provides multiple benefits such as recreation, food, health, tourism, jobs and drinking water (UNEP 2021a). Sidik (2022) noted that spillover benefits of climate action may save millions of lives in Africa. This, among other advantages, amplifies the recognition of the benefits associated with climate change adaptation and mitigation across the continent, and serves as a catalyst for taking action on the same.

Conclusion and recommendation

Climate change has devastating impacts, especially on developing countries. The situation may worsen in the future since climate projections show a high likelihood of decreased precipitation and increased temperatures over most parts of Africa. In response, many countries are trying to build resilience to climate change. Although adaptation measures are context-specific, initiatives focusing on agriculture and water conservation are key since they support nearly all socio-economic sectors and the environment. Thus, it is important to take stock of climate change adaptation and mitigation strategies to identify opportunities and solutions to the challenges.

Mapping and utilizing natural resources such as solar renewable energy in Morocco contributes to climate change mitigation and overall socio-economic development. This is an avenue that can be explored by most developing countries to produce local solutions to climate change and spur socio-economic development. This requires data to support research on the potential of natural resources and feasibility of the proposed initiatives. This data, as well as climate data, is generally limited, calling for efforts to improve its quality, and making it available for use. In some cases, there are no enabling policies to support mapping and utilization of natural resources in climate change adaptation and mitigation. These can become a reality with good governance systems in place.

Since Morocco deals with a multitude of climate finance providers with often different investment criteria or project approval procedures, it is advisable to designate a single agency with the ability to reach and include a wide swath of national and local stakeholders as the national climate finance coordination body. In following the example of other countries on the African continent, such a body could be set up as the National Climate Fund and serve as the central recipient of all international public climate finance inflows.

Involving all stakeholders in addressing environmental issues, especially local populations, promotes ownership and sustainability. In Morocco, government initiatives, with the support of the private sector through a public–private partnership, are playing an essential role in establishing wind power plants across the country and launching the Green-Hydrogen initiative. The returns of adaptation and/or mitigation initiatives may be short or long term. Thus, the initiatives require policies and regulatory frameworks that integrate them into development goals. Thus, there is a need for strong climate change policies, which are lacking in most countries across the continent (Abraham 2018). In Morocco, economic inequality and social inclusion remain a weakness, calling for concerted efforts through supportive policies and legal frameworks to achieve SDG5 on gender equality and women and girls' empowerment.

This work does not highlight some of the community-initiated small-scale projects to address climate change across Morocco because the interest is in showcasing the role of the government in responding to and mitigating climate change. It is worth noting that as climate change impacts increase, more people are pushed into embracing adaptation and mitigation measures at the household level based on their needs. Strategies such as agroforestry systems and sustainable forests at the local level enhance resilience among vulnerable households across sub-Saharan Africa (Oeba and Larwanou 2017). Most of these practices depend on indigenous knowledge not covered herein, yet important in addressing climate change.

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