The impact of climate change on budget balances and debt in the Middle East and North Africa (MENA) region

Eleftherios Giovanis1 · Oznur Ozdamar2

Abstract
Lower tax revenues and greater government spending result in higher deficits and public debt. As a result, determining the degree of budgetary effects is vital, but important to assess the persistence of these effects. We aim to investigate the impact of climate change on the fiscal balance and public debt in the countries of the Middle East and North Africa. The empirical analysis relies on panel data in the period 1990–2019 and employs various models. The findings show that temperature changes adversely affect the government budget and increase debt, but we find no significant impact of changes in rainfall. The average temperature decreases fiscal balance by 0.3 percent and increases debt by 1.87 percent. Using projections of temperature and rainfall over the years 2020 to 2099, we find a significant decrease in the fiscal balance at 7.3 percent and an increase in the public debt at 16 percent in 2060–2079 and 18 percent in 2080–2099 under the assumption of a high greenhouse gas (GHG) emission scenario. On the contrary, under the low GHG emission scenario, the fiscal balance deteriorates by 1.7 percent in 2020–2039 and 2.2 percent in 2080–2099, while public debt rises by 5 percent in 2020–2039 and 6.3 percent in 2080–2099.

Keywords Budget balances · Climate change · Middle East and North Africa region · Public debt · Standardized precipitation index · Stationarity

1 Introduction
The need for balance in public spending and tax revenues at the national level is paramount for fiscal sustainability in many countries. This is challenging even in the best of times. However, with climate change, governments will face severe pressure to increase public expenditures, such as household disaster relief and reconstruction of the
infrastructure (Perry and Ciscar, 2014). Climate change may also affect different sectors of the economy, such as agriculture and tourism (Aaheim et al., 2012; Ciscar et al., 2014), reducing the tax base and exacerbating budgetary imbalances. In the sense that these impacts are transitory, growth in public debt will spread the financial effort over time. But, if climate change effects are permanent, governments and policymakers cannot justify an increase in public debt.

World leaders and experts recognize that, apart from other natural factors, human actions and industrial activities are causing carbon dioxide emissions and other greenhouse gases that accumulate in the atmosphere. A report conducted by the Intergovernmental Panel on Climate Change (IPCC, 2021) estimates that global temperatures will rise by 1.3 to 2.4 °C on average in the period 2020–2060 and by 1.9 to 5.7 °C in 2061–2100 in the absence of pollution reduction and emission control policies. According to a World Bank report, crop yields could drop by up to 30 percent at an increase of temperature at 1.5–2 °C and over 60 percent at a temperature rise of 3–4 °C (World Bank, 2016).

Drawing on studies that look at the historical relationship between regional output and regional temperature and precipitation, as well as projections for the future, in the USA, climate change will reduce real gross domestic product (GDP) by 1 percent in 2050. Changes in temperature and precipitation account for 0.8 percent of the 1 percent, while hurricane damage accounts for 0.2 percent, implying a pressure on the government budget by the reduction in income tax and allocation of extra expenditures to mitigate the climate change effects (Herrnstadt and Dinan, 2020; Congressional Budget Office, 2021).

Extreme weather events and extreme temperatures and droughts because of climate change have significant adverse budgetary and debt effects. Officials estimate that the US government has to allocate between $9 and $28 billion per year of the annual expenditures to wildland fire suppression, crop insurance, coastal disaster relief, air quality and healthcare. These costs may double in the period 2060–2100. Osberghaus and Reif (2010) provide estimations about the budgetary effects and adaptation costs to climate change in the countries of the European Union (EU), which may amount up to €5.7 billion in 2050 and €4 billion in 2060–2070.

Most of the studies have explored the climate change impact on GDP and not on fiscal balances and government budgets. The study by Bachner and Bednar-Friedl (2019) is one of the few comprehensive analyses estimating the direct and indirect budgetary effects. The authors found that Austria’s government budget in 2050 will decrease by 1.2 percent. This finding is part of the direct effects that includes the increase in expenditures related to climate-induced relief payments by 184 percent and a 10.6 percent increase in expenses related to unemployment benefits caused by the adverse effects of climate change on the production process. The reduction in government expenditures may reach 1.4 percent, which refers to the non-climate public consumption reduction since the government may need to compensate for the increase in climate-related expenses.

Extreme temperatures are frequent in the Middle East and North Africa (MENA) countries. In the following decades, experts expect these extremes will only worsen. Changes in precipitation patterns, drought increase and water scarcity will pose substantial difficulties to the region’s development, particularly in agriculture, food security and livelihoods. The motivation for exploring the impact of climate change on the fiscal sustainability of MENA region countries is the increasing trend of droughts and water scarcity. In particular, the MENA region is the most water-scarce in the world, home to about 6.5 percent of the world’s population. Eleven of the 17 most water-stressed countries worldwide belong to the MENA region, and 17 out of 21 MENA countries have crossed the “water poverty/scarcity” threshold set by the United Nations Food and Agriculture Organization (FAO) (World
Bank, 2012, 2018). Over 60 percent of the region’s population lives in high and very high water-stressed areas compared to the global average of 35 percent. These water-stressed areas generate more than 70 percent of the region’s GDP compared with a worldwide average of 22 percent (World Bank, 2018). While the MENA economies rely on oil reserves and exports, they likewise produce and export agricultural goods. The agricultural sector contributes roughly 6 percent of the region’s GDP. It also employs around 13 percent of the population, ranging between 1 percent in Bahrain and 33 percent in Morocco.

Tourism is another economic pillar in these countries and has become a strategic part of the diversification of oil production. The region shares vast heritage and cultural and natural tourism assets and offers top attractions hosting cultural, sports and shopping facilities. In 2019 MENA region represented 5 percent of the world’s population of tourists. The receipts were 6 percent of the world’s tourism earnings, and the combined GDP in 2017 accounted for 3 percent of the world’s economy GDP. On average, in 2019, tourism contributed 9 percent of the MENA region’s GDP 2019 (World Tourism Organization, 2019). Yet, both the agricultural and tourism sectors rely on water resources. Agriculture dominates as the largest water-consuming sector in the MENA countries at 82%, even though the water demand may reduce by 67% in 2050 (Mualla, 2018), while tourism requires water resources as well (Kliot, 2018).

Extensive droughts, rising in temperature and extreme weather events will hurt agriculture production and the tourism sector, which will reduce GDP. Thus, the countries may experience a decline in the fiscal budget because of a reduction in government income and corporation tax revenues and an increase in the government expenditures allocated to unemployment benefits and transfer programmes due to employment loss in these sectors. The indirect effects include further deterioration in other sectors because of employment and income loss.

The second reason we explore MENA region countries is that a large part of their economy relies on oil reserves and exports, contributing on average to 16 percent of the GDP in 2019, and the employment share in this sector ranges between 10 and 35 percent (IEA/OECD, 2018). A significant impact on GDP and, thus, on government revenues, fiscal balance and debt is the significant long-term deceleration in the growth of global oil demand. In particular, because of climate change, efforts to improve energy efficiency and increase the use of alternative renewable energy resources and substitution away from oil are taking place in MENA countries and countries around the globe (ILO, 2018). This may have a similar effect to the COVID-19 pandemic that reduced oil demand, production and employment, causing further a decline in oil revenues and increasing expenditure needs. Consequently, government budget deficits in MENA region countries widened to 10.1 percent of the region’s GDP in 2020 from 3.8 percent in 2019 (Better, 2020; IMF, 2021). In 2022 oil prices follow a large recovery, and increases in energy prices will have a further adverse effect on the economy. These price increases will cause inflation around the globe by increasing the cost and, thus, the price of the final products since energy is one of the main factors of production.

To the best of our knowledge, so far, there is no study exploring the effects of climate change on debt and public finances in the MENA region. Studies have documented budgetary and debt effects of climate change in the USA, Europe, Latin America and the

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1 These countries belong to the Organization of the Petroleum Exporting Countries (OPEC) and the Gulf Cooperation Council (GCC).
2 https://data.worldbank.org/indicator
Caribbean (LAC) countries (Lis and Nickel, 2010; Acevedo Mejia, 2014, 2016; Cevik and Nanda, 2020; Congressional Budget Office, 2021). Our findings show a significant temperature impact on fiscal balance and the debt-to-GDP ratio, but we report no rainfall effect. In the short-term period, we find that a 1 °C increase in the average temperature reduces fiscal balance by 0.04 percent. In the long run, the reduction of fiscal balance can reach 0.30 percent. Average temperature increases the debt-to-GDP ratio by 1.87 percent in the long-run period. The increase may reach 2.5 percent in the short-run period. Using projections on the temperature and rainfall over 2020–2099 under different greenhouse gas (GHG) emissions scenarios, we find that the fiscal balance will decline by 2.3 to 7.3 percent, while the public debt will increase by 6 to 18 percent. These scenarios show the impact on economic activity and public debt if governments do not undertake policies focusing on the challenges posed by climate change.

The structure of this study is as follows: In Sect. 2, we briefly discuss the literature review of the climate change impact on fiscal balances and debt. Then, we present the data and the main regression specifications applied in the empirical analysis in Sect. 3. In Sect. 4, we report the empirical results, and in Sect. 5, we discuss the main concluding remarks.

2 Literature review

Policymakers are becoming deeply involved in the implications and consequences of climate change. Recent studies have examined the need for climate change mitigation and adaptation policies by underlining that climate change causes adverse supply shocks, which trigger a decline in global economic growth (Stern, 2008; Lis and Nickel, 2010; Botzen et al., 2019; Krogstrup and Oman, 2019; Kahn et al., 2021). A literature review by Krogstrup and Oman (2019) reveals the losses in GDP range between 0 and 3 percent for every 3 °C of global warming. Other studies show that the effect of climate change and vulnerability varies across countries. In particular, the most disadvantaged tend to be the developing countries since they have warmer climates, poor initial macroeconomic conditions, poverty and higher levels of income inequality (Strömberg, 2007; Acevedo Mejia, 2016; Acevedo Mejia et al., 2018).

In Table 1, we report a summary of studies exploring the impact of climate change, temperature and precipitation, extreme weather events and natural disasters on various economic and fiscal outcomes. These include the fiscal balance, debt, GDP per capita regional expenditures and damages as a ratio of GDP. The results vary by the climate change measure, the countries explored and methods. However, all studies share similar concluding remarks. For instance, Lis and Nickel (2010), Acevedo Mejia (2016), Leppänen et al. (2017), Acevedo Mejia et al. (2018), IMF (2016, 2019, 2020) and Cevik and Jalles (2020) have applied panel data regressions, including fixed effects, generalized method of moments (GMM), vector autoregression (VAR) and auto-regressive distributed lag (ARDL) models. The findings show that small countries, especially the Caribbean and Latin American countries, are more vulnerable to storms and floods. Countries in the MENA region, sub-Saharan Africa, and those near the equator have experienced a larger reduction in GDP per capita and an increase in public deficits and debt compared to North European and North American countries.

Hinkel et al. (2014a, b), Cantelmo et al. (2019), Bachner and Bednar-Friedl (2019) and Parrado et al. (2020) have employed computable general equilibrium (CGE) and calibrated models. Even though these studies use different methods, the main conclusion is that
| Authors                  | Study design                        | Countries-period                                                                 | Climate change measure                                      | Outcome measure          | Summary of findings                                                                                                                                                                                                                                                                                                                                 |
|-------------------------|-------------------------------------|----------------------------------------------------------------------------------|-------------------------------------------------------------|--------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Kahn et al. (2021)      | Auto-regressive distributed lag (ARDL) panel data model | 174 developing, emerging and developed economies in 1960–2014                     | Deviations of temperature and precipitation from their historical norms | GDP per capita            | Persistent fluctuations in temperature (above or below their historical norm) have a negative impact on per-capita real production growth, but variations in precipitation have a statistically insignificant effect on growth. In the absence of mitigation, a 0.04 °C annual increase in average global temperature will reduce the world real GDP per capita by 7.22% by 2100. On the other hand, adhering to the Paris Agreement, which limits global warming to 0.01 °C every year, cuts the loss to just 1.07% |
| Parrado et al. (2020)   | Computable general equilibrium (CGE) model | Various regions, including North, South and sub-Saharan Africa, Middle East, EU 15, USA, China and others in 2007–2050 | Sea level rise                                              | Fiscal indicators, public deficits, government bonds and GDP growth | The study finds that all regions in the world will suffer a loss and experience an increase in economic growth, public deficits and debt, with the most affected regions being China and South Asia. The GDP growth reduction may reach up to 10 percent in China by 2050 and 6–8 percent in South Asia, 2–4 percent in the MENA region and around 1–5 percent in the rest of the world. In 2050, the public expenditures will amount to more than $800 billion in China, $236 billion in Latin America and the Caribbean, $180 billion in India, $171 billion in East Asia and around $110 in MENA countries |
| Authors                | Study design                                      | Countries-period                                      | Climate change measure                              | Outcome measure                        | Summary of findings                                                                 |
|-----------------------|--------------------------------------------------|------------------------------------------------------|-----------------------------------------------------|----------------------------------------|-------------------------------------------------------------------------------------|
| IMF (2020)            | Panel data regressions                            | 69 developing, emerging and developed economies in 1970–2018 | Extreme weather events, as floods, storms, heatwaves, droughts | Damages as proportion of GDP            | Developing and emerging economies have been hit harder by climate change and extreme weather events than advanced economies, by experiencing almost double damages at 0.13 percent of the GDP, compared to 0.07 percent for the advanced economies. |
| Cevik and Jalles (2020)| Panel data—generalized method of moments (GMM) and two-stage least squares (2SLS) | 98 advanced and developing countries over the period 1995–2017 | Vulnerability and resilience to climate change as measured by the Notre Dame Global Adaptation Index (ND-GAIN) | Sovereign bond risk and cost of government borrowing | The authors found that vulnerability and resilience to climate change have a significant effect on the sovereign bond risk and the cost of government borrowing. These implications are even more pronounced in developing countries with little capacity to adapt to and mitigate climate change’s effects. One percentage point rise in climate change vulnerability is linked to a 0.58 percent increase in long-term government bond spreads, while a 1 percent increase in climate change resilience is linked to a 0.15 percent reduction in long-term government bond spreads. |
| Authors          | Study design          | Countries-period                              | Climate change measure                                           | Outcome measure | Summary of findings                                                                                                                                                                                                 |
|------------------|-----------------------|-----------------------------------------------|-------------------------------------------------------------------|-----------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Cantelmo et al. (2019) | Model calibration    | 129 low- and middle-income economies in 1998–2017 | Extreme weather events and natural disasters, such as droughts, floods and storms | Public debt   | Affected countries experience a permanent loss in consumption of 1.6 percent and a reduction in growth on average by 1 percent compared to the non-disaster-prone countries. This leads to a significant fall in output which in turn translates into lower government revenues and thus a lower fiscal balance and higher public debt. Countries vulnerable to climate change effects have a public debt of 1.54 percentage points of GDP higher than non-disaster-prone countries, which can increase to an 11 percent debt-to-GDP ratio when a climate change scenario is considered. In particular, the climate scenario assumes a higher disaster probability at 35 percent and higher average damages of 82 percent |
| Authors                  | Study design                        | Countries-period | Climate change measure                                      | Outcome measure | Summary of findings                                                                                                                                 |
|-------------------------|-------------------------------------|------------------|------------------------------------------------------------|-----------------|-----------------------------------------------------------------------------------------------------------------------------------------------------|
| Bachner and Bednar-Friedl (2019) | Computable general equilibrium (CGE) model | Austria          | Extreme weather events and natural disasters, i.e. floods and storms | Fiscal balance  | Climate change may increase expenditures on unemployment benefits due to lower aggregate output by 10 percent leading to a decrease in the total government budget by 0.3 percent. However, there are also indirect effects, as climate-related expenditures should be compensated by the reduction in the provision of public services related to non-climate government consumption. Lower levels of consumption limit labour demand and, consequently, labour tax income because non-climate government consumption is generally labour intensive |
Table 1 (continued)

| Study details | Study design | Countries-period | Climate change measure | Outcome measure | Summary of findings |
|---------------|--------------|------------------|------------------------|-----------------|-------------------|
| IMF (2019)    | Literature review | 64 emerging and developing economies | Natural disasters and extreme weather events, such as droughts, floods, storms, tsunami and earthquakes | Fiscal balance and debt-to-GDP ratio | The results vary by region and type of natural disaster. Caribbean and Pacific small states are more vulnerable to extreme weather events and have experienced higher adverse climate change effects. For instance, in Fiji, the government spending on resilience grew fourfold in 2012–2016 to about US$170 million—a tenth of the government budget in 2017. Droughts are other significant consequences of climate change. For instance, Ethiopia would have to more than double its annual public expenditures on climate adaptation, which are US$400 million or 0.5 percent of GDP, to fully implement the authorities' strategy for mitigating the impact of droughts on agriculture. Sustaining resilient investment will require an increase of around 2.8 percent of GDP annually in Dominica to meet the public debt target of 60% of GDP by 2030 corresponding to about US$200 million cumulatively |
| Study details        | Study design                        | Countries-period          | Climate change measure                                      | Outcome measure                  | Summary of findings                                                                                                                                 |
|---------------------|-------------------------------------|---------------------------|-------------------------------------------------------------|----------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------|
| Acevedo Mejia et al. (2018) | Panel vector autoregression (PVAR) model | 40 countries in 1950–2012 | Average temperature and precipitation                      | GDP per capita                   | The results show that a rise in temperature lowers per capita output, in both the short and medium term, and thus decreases the government budget. In particular, for the emerging economies, a 1 °C increase from a temperature of the median of 22 °C lowers growth by 0.9 percentage points, and for the low-income countries, an increase from a temperature of the median of 25 °C growth falls by 1.2 percentage points. Acevedo Mejia et al. (2018) found a significant quadratic relationship between real output per capita and temperature with a turning point at 13–15 °C. This implies that the growth increases with rising temperature up to this point, and then a negative impact of temperature on output growth is observed. On the other hand, they found no significant linear or quadratic relationship for the precipitation. |
| Leppänen et al. (2017)  | Panel data fixed effects             | Regions in Russia in 1995–2009 | Average temperature and precipitation                      | Regional expenditures            | The authors estimate the effect of short-term variation and medium-term changes in climatic conditions. Using a mild climatic scenario that slightly exceeds 1 °C, the increase in temperature reduces expenditures, and the economy saved over USD 2 billion to USD 4 billion in the period 2000–2020. |
| Acevedo Mejia et al. (2016) | Panel vector autoregression (PVAR) model | 12 Caribbean countries in 1970–2009 | Natural disasters, such as floods and storms               | GDP growth and debt-to-GDP ratio | The study finds that floods and storms have a negative effect on GDP growth by around 0.7 percent. Debt increases with floods by around 3–5 percent, but not with storms. |
| Study details          | Study design                                                                 | Countries-period                                                                 | Climate change measure          | Outcome measure                  | Summary of findings                                                                 |
|-----------------------|------------------------------------------------------------------------------|----------------------------------------------------------------------------------|--------------------------------|----------------------------------|-------------------------------------------------------------------------------------|
| Hinkel et al (2014a, b) | Simulations using the WRCP Coupled Model Intercomparison Project—Phase 5 (CMIP5) | Coastal countries and regions. Global mean sea-level rise in 2100 with respect-reference to 1985–2005 | Coastal flooding               | Damages as ratio of GDP          | This study explores the impact of sea-level rise and coastal flooding on the damages per GDP. The authors account for a wide range of uncertainties in continental topography data, population data and socioeconomic development. They found that without adaptation, 0.2–4.6% of the global population is expected to be flooded annually in 2100 under 2.5–123 cm of global mean sea-level rise. The expected costs and losses may reach between 0.3 and 9.3 percent of the global gross domestic product |
| Lis and Nickel (2010)  | Panel data-fixed effects and two-stage least squares (2SLS)                   | 138 emerging, developing and developed economies in 1985–2007                    | Extreme weather events, i.e. droughts, extreme temperature, flood, mass, storm and wildfire | Fiscal balance                   | The study finds that extreme weather events have a significant and negative budgetary impact, ranging between 0.23 and 1.1% of GDP depending on the country group. In particular, the reduction reaches 0.23% when the authors consider the full sample, while when the sample is split into young democracies and developing economies, the impact rises to 0.47% of GDP and for the developing economies to 1.1%. Furthermore, countries with a warmer climate and those nearer the equator are more vulnerable |
economies in South Asia, the Caribbean, Latin America, Africa and the Middle East are more vulnerable to climate change and extreme weather events. These countries will experience larger declines in GDP per capita. The drop in GDP growth may reach 10 percent in China, 6–8 percent in South Asian countries and 2–4 percent in MENA region countries by 2050, while the debt-to-GDP ratio can reach 11 percent. This study aims to contribute to the previous literature by exploring the impact of climate change on the fiscal sustainability of MENA region countries. Furthermore, we perform regressions using various proxies for climate change as robustness checks and apply a rich set of panel data models.

3 Methodology and data

3.1 Impact of climate change on fiscal balance and debt

Fiscal sustainability is a goal for many countries, and it requires a balance between tax revenues and government expenditures. Climate change can influence economic activity, fiscal balances, and debt through various channels. The most obvious is the effect on agricultural production, given that temperature and precipitation are direct inputs in crop production and tourism (Aaheim et al., 2012). This reduction in sectoral output reduces tax revenues by reducing the tax base, exacerbating the imbalance between higher expenditures and lower revenues. Research finds broader effects, including labour productivity, health, mortality and conflict (Deschenes, 2014; Burke et al., 2015). According to evidence from surveys and other sources, exposure to heat above a specific point affects people’s performance on both cognitive and physical tasks (Seppänen et al., 2006; Graff Zivin et al., 2018). Health positively affects economic growth by reducing production losses owing to worker illness, lowering absenteeism rates, increasing productivity because of improved nutrition and enhancing learning among school children. This became clear from the COVID-19 pandemic that has affected economic growth, health and learning outcomes, which reduced revenues through income tax, productivity losses, increased expenditures related to poor health and increased debt levels (Hanushek and Woessmann, 2020). Productivity may further decline if climate change and extreme weather events provoke political instability, incite conflict or undermine governing institutions in other ways, affecting economic growth, fiscal balances and debt (Deschenes, 2014; Burke et al., 2015).

Thus, climate change has two adverse effects on fiscal balance. First, it may lead to higher public expenditures, including unanticipated needs for immediate social protection, rehabilitation and disaster relief payments to households, or infrastructure reconstruction (Perry and Ciscar, 2016; Bachner and Bednar-Friedl, 2019), causing an imbalance in public budgets. Second, following the evidence in the earlier studies (Deschenes, 2014; Burke et al., 2015; Graff Zivin et al., 2018), the effect on fiscal balance is negative, because of the lower economic growth, and public revenues, and, thus, lower income tax base. In the long term, the costs of climate change and extreme weather events contribute to the ratcheting up of public debt (Acevedo Mejia, 2014). Climate change and extreme weather events harm sovereign assets, increase public debt and exacerbate a financial crunch. The consequent shock to budgetary solvency and liquidity requires a pro-cyclical policy reaction, limiting reconstruction options and slowing economic recovery. This, in turn, increases a country’s vulnerability to climate change, limiting recovery options, particularly for
countries that rely heavily on external funding (IMF, 2016), which is likewise the sample of MENA nations studied in this study.

3.2 Main specification

We first investigate the relationship between budget balance, temperature and rainfall by estimating the following regressions.

\[ y_{it} = a + \beta_1 \text{Temperature}_{it} + \beta_2 \text{Rainfall}_{it} + \beta X_{it} + \mu_i + \delta_t + \epsilon_{it} \] (1)

where \( y \) is the outcome explored, and in particular, we will explore the change in budget balance as a share of GDP in the country \( i \) at year \( t \).

The second outcome is the public debt-to-GDP ratio. Population-weighted average temperature, measured in Celsius, is calculated by taking the average monthly values for each year. Similarly, population-weighted average rainfall, which is measured in millimetres (mm), is calculated by taking the average monthly values, while \( X \) is a vector of control variables. For robustness check, we will also consider the variation of the weather variables, and in particular, we will take the standard deviation over the previous 3 and 5 years (Vinnikov and Robock, 2002; Boer, 2009). Evidence shows that variation, measured by standard deviation, is a useful measure of climate change instead of the mean temperature and rainfall. Finally, we include sets \( \mu_i \) and \( \delta_t \) that represent the country and time-fixed effects to account for unobserved variables correlated with extreme weather events and economic situations.

We estimate the benchmark model using ordinary least squares (OLS) with country and year fixed effects (FE). To account for past occurrences and the historical perspective of the phenomenon, we add the lagged dependent variable on the right-hand side of the regression (1) and apply the generalized method of moments (GMM) method. Other models include the random effects and the feasible generalized least squares (FGLS) that account for the presence of heteroskedasticity, serial and cross-sectional correlations (Bai et al., 2021). We also apply the panel-corrected standard errors (PCSE) to control for contemporaneous correlation across countries (Beck and Katz, 1995, 1996). We implement the Prais-Winsten regression to correct autocorrelation since we have an autoregressive process of order one AR(1).

3.3 Control variables

Following the earlier literature (Tujula and Wolswijk, 2004; Mayes and Viren, 2004; Lis and Nickel, 2010; Ghosh et al., 2013; Wehner and de Renzio, 2013; Krogstrup and Oman, 2019; Cevik and Jalles, 2020) and data availability, the control variables include real GDP growth rate, the unemployment rate, inflation, the Polity index and the debt-to-GDP ratio. We remove the last variable when we consider it as the dependent variable. The real GDP growth rate and unemployment rate measure the fiscal responsiveness to macroeconomic conditions. They primarily operate through automatic stabilizers, tax revenues and unemployment-related expenditures. Discretionary fine-tuning efforts may have an additional effect, and anti-cyclical strategies strive to keep economic growth at a level that is close to the potential output. This calls for higher deficits in recession periods, whereas in a boom, a contractionary budget aids in damping cyclical upturns and avoiding economic overheating. In recessions, governments implement expansionary
policies to address downturns, but during economic upturns, they use cyclical budgetary proceeds to increase expenditures or cut taxes rather than for additional consolidation (Viren, 2000; Mayes and Viren, 2004).

Inflation affects the budget balance through the nominal progression of tax rates and tax brackets and price indexation of revenues and expenditures. As a result, it has an automatic effect on government receipts and expenditures. A second channel through which inflation operates is that it causes governments to adjust policies. High inflation, for example, erodes competitiveness and risks, putting pressure on fixed exchange rates in countries that participate in an exchange rate agreement (Kontopoulos and Perotti, 1999). It might also lead to a spike in long-term interest rates, which would be detrimental to investment and economic growth. On the other hand, governments may favour inflation because it reduces the real value of nominal government debt. As a result, the overall impact of inflation on budget balances is not a priori clear (Tujula and Wolswijk, 2004).

We consider democracy as another determinant of fiscal balance. As a proxy, we use the composite Polity index that ranges from −10 to 10, with higher values reflecting more democratic countries. We derive the index from the Center for Systemic Peace. The Polity IV index provides a minimalist definition of democracy mainly based on elections and political competition and participation (Munck and Verkuilen, 2002). The principal assumption is that governments in countries with no free and fair elections are not committed to providing open access to information about their activities and a transparent budget to increase rent-extraction opportunities. As a result, a lack of fiscal openness may result in a rise in governmental debt (Alt and Lassen, 2006; Benito and Bastida, 2009; Wehner and de Renzio, 2013). Fiscal transparency is typical when well-established democratic institutions exist. Governments prefer to reveal trustworthy information to the public to reduce the risk of impeachment for poor fiscal performance and inadequate public finance management (Hameed, 2005; Harrison and Sayogo, 2014). This may induce lower levels of public debt. A more transparent government is more fiscally disciplined, and if it produces high-quality budget execution data, there is a lower probability of a large surprise deficit. If politicians seek reelection, the higher the corruption, associated with higher levels of deficit and debt, the lower the probability for the politicians to be elected again (Hameed, 2005; Ferraz and Finan, 2008).

The debt-to-GDP ratio reflects concerns about the fiscal policy’s long-term sustainability. The direction of the relationship is indeterminate. A higher debt-to-GDP ratio could lead to an improvement in the budget. However, a higher debt ratio raises interest payments, causing the fiscal balance to deteriorate (Tujula and Wolswijk, 2004). Melitz (2000), Ghosh et al. (2013) and Cevik and Nanda (2020) have suggested a quadratic formulation, but we find an insignificant estimated coefficient of the quadratic term.

In principle, demographic trends have a first-order effect on the budget. The standard proxy in the literature (Shelton, 2007; Leppänen et al., 2017) is the old-age dependency ratio, defined as the number of economically inactive individuals [over 64] relative to prime-aged individuals [15 and 64]. We express this indicator per 100 persons of working age 15–64. However, we find an insignificant effect since the ageing population is an issue in developed economies.

3 https://www.systemicpeace.org/polityproject.html
4 https://ec.europa.eu/eurostat/web/products-datasets/-/tps00198
3.4 Unit root tests and autoregressive distributed lag (ARDL)

We should highlight that using the methods we described above will lead to spurious regressions, given that the number of countries \((N = 18)\) is smaller than the time dimension \((T = 30)\). Thus, we will test for stationarity and whether the series are co-integrated. Then we will apply the autoregressive distributed lag (ARDL) model. This model is preferable since it can deal with variables that are integrated of a different order, as at levels I(0) or first difference I(1) or a combination of both, and is robust when there is a single long-run relationship between the underlying variables in a small sample size (Pesaran et al., 1996, 2001; Pesaran and Shin, 1999; Hassler and Wolters, 2006). Because ARDL and unit root tests are well-documented, and since it is out of the study’s main objectives, we do not discuss in more detail these approaches.

Since the seminal works by Quah (1994) and Levin et al. (2002), the study of unit roots has played an increasingly important role in the empirical analysis of panel data. Indeed, the investigation of integrated series in panel data has known a significant development, and many studies have applied panel unit root tests to various fields of economics. Adding the cross-sectional dimension to the usual time dimension is very important in the context of nonstationary series. The first generation of panel unit root tests is based on the cross-sectional independence hypothesis (Harris and Tzavalis, 1999; Maddala and Wu, 1999; Choi, 2001; Hadri, 2000; Levin et al., 2002; Im et al., 2003). We will implement the Pesaran (2021) cross-section dependence (CD) test to illustrate whether we need to apply first- or second-generation unit root tests. The long-run relationship using the ARDL is:

\[
bb_t = a + \beta_0 bb_{t-1} + \sum_{i=1}^{m} \beta_i Temperature_{t-1} + \sum_{i=1}^{n} \gamma_i Rainfall_{t-1} + \sum_{i=1}^{j} \delta_i \Delta X_{t-1} + \mu_i + \delta_i + \epsilon_a
\]  

(2)

where the variables are defined as in (1).

As we discuss in the next section, we will estimate (2) using the order of integration based on the unit root test, and we will also include the first differences. The short run and the vector error corrections ARDL, denoting the first difference as \(\Delta\), is:

\[
\Delta bb_t = a + \lambda_0 \Delta bb_{t-1} + \delta_0 EC_{t-1} + \sum_{i=1}^{m} \delta_i \Delta Temperature_{t-1} + \sum_{i=1}^{n} \gamma_i \Delta Rainfall_{t-1} + \sum_{i=1}^{j} \beta_i \Delta X_{t-1} + \mu_i + \delta_i + \epsilon_a
\]  

(3)

3.5 Projections of fiscal balance and debt

The second objective of this study is to project the paths of debt and budget balance over the years 2020–2099. We use the average projections over four sub-periods [2020–2039, 2040–2059, 2060–2079 and 2080–2099] provided by the World Bank. Then, we present the impact in four scenarios of emissions: a stringent mitigation scenario with low GHG emissions (RCP2.6), two intermediate scenarios (RCP4.5 and RCP6.0) and one high GHG emissions scenario (RCP8.5). Scenario RCP8.5, known as “business as usual”, represents the outcome if society makes no concerted effort to cut greenhouse gas emissions (Pachauri et al., 2014).

RCP2.6 reflects a scenario that aims to keep global warming below 2 °C, ranging between 0.4 and 1.6 °C, above pre-industrial temperatures. Most models under the specific scenario show substantial net negative emissions achieved when more GHGs are sequestered than are released into the atmosphere by 2100, an average of around 2 gigatonnes of carbon dioxide per year (GtCO₂/year). Scenarios RCP4.5 and RCP6.0 predict a likely
range of temperature between 0.9 and 2.0 °C in 2046–2065 and 1.1 to 2.6 °C in the period 2081–2100. The scenario of high emissions RCP8.5 projects an increase in average temperature ranging between 1.4 and 2.6 °C in 2046–2065 and 2.6 to 4.8 °C in 2081–2100 (Pachauri et al., 2014). Yet, this seems to be the least realistic scenario (Hausfather and Peters, 2020).

3.6 Data

We derive the weather data and, in particular, the monthly 0.5° × 0.5° gridded average temperatures and rainfall, from the Climate Change Knowledge Portal of World Bank (https://climateknowledgeportal.worldbank.org/), provided by the Climatic Research Unit (CRU) of the University of East Anglia (UEA). Then, following the estimates, we will include the projections of temperature and rainfall from the Climate Change Knowledge Portal to investigate the impact on the debt and budget balance from 2020 to 2099.

Data related to debt and budget balances are available from the International Monetary Fund (IMF). For the control variables, we got the data from the World Development Indicators (https://datatopics.worldbank.org/world-development-indicators/) and the International Monetary Fund (IMF) during 1990–2019. Based on the data availability, we explore 17 MENA countries and Turkey, and these are Algeria, Bahrain, Djibouti, Egypt, Iran, Israel, Jordan, Kuwait, Lebanon, Libya, Morocco, Oman, Qatar, the United Arab Emirates, Saudi Arabia, Tunisia and Yemen in the period 1990–2019. The main underlying reason for limiting the analysis to those countries is the availability of general government fiscal balance data starting in 1990 and available for all countries. Regarding Iraq, the data become available after 2003, while for Syria, there is no information on debt and budget balances from 2010 to 2019. So, we do not include these countries in our analysis.

4 Empirical results

4.1 Impact of temperature and rainfall on fiscal balance and public debt

In Table 2, we report the estimates derived from various panel data models for the fiscal balance. In Table 3, we repeat the regressions for the debt-to-GDP ratio. The models include the OLS fixed effects (FE), random effects (RE) and the panel-corrected standard error (PCSE) model with a panel-specific autocorrelation of order 1 (AR1) structure. The fourth model is a feasible generalized least squares (FGLS) considering heteroskedastic with cross-sectional correlation panels and AR1 structure. The last model is the generalized method of moments, used to account for the potential inconsistency and comprise the bias of OLS in the presence of a lagged dependent variable in the dynamic fixed-effects models (Nickell, 1981).

We observe similar results across the various panel data models. We find a significant impact of the average temperature on fiscal balance, ranging between a 0.025 and 0.04% reduction. On the contrary, we found a negative estimated coefficient for the rainfall, but it is insignificant in all model specifications. Thus, if we consider, for example, the OLS with time and country fixed effects estimates in panel A, if the average temperature increase by 1 °C, then the annual fiscal balance will reduce by 0.03 percent. As we have highlighted,
| Panel A: Average weather variables | Fixed effects (FE) | Random effects (RE) | Panel-corrected standard errors (PCSE) | Feasible generalized least squares (FGLS) | Generalized method of moments (GMM) |
|-----------------------------------|-------------------|--------------------|--------------------------------------|------------------------------------------|----------------------------------|
| Fiscal budget 1-year lagged       |                   |                    |                                      |                                          | 0.7301*** (0.0368)               |
| Average temperature               | $-0.0357^{**}$ (0.0153) | $-0.0319^{**}$ (0.0132) | $-0.0398^{**}$ (0.0173) | $-0.0252^{*}$ (0.0133) | $-0.0324^{*}$ (0.0141) |
| Average rainfall                  | $-0.0058$ (0.0130) | $-0.0044$ (0.0059) | $-0.0034$ (0.0052) | $-0.0044$ (0.0037) | $-0.0196$ (0.0236) |
| Real GDP growth rate              | $0.0213^{***}$ (0.0045) | $0.0210^{***}$ (0.0056) | $0.0260^{***}$ (0.0057) | $0.0145^{***}$ (0.0038) | $0.0466^{**}$ (0.0221) |
| Unemployment rate                 | $-0.0370^{*}$ (0.0213) | $-0.1204^{***}$ (0.0404) | $-0.0427^{**}$ (0.0212) | $-0.0171^{***}$ (0.0075) | $-0.0409^{**}$ (0.0196) |
| Inflation rate                    | $-0.0078$ (0.0068) | $-0.0039$ (0.0071) | $-0.0067$ (0.0050) | $-0.0054$ (0.0042) | $-0.0406$ (0.0377) |
| Polity IV                          | $0.0201^{**}$ (0.0092) | $0.0230^{**}$ (0.0091) | $0.0192^{**}$ (0.0096) | $0.0212^{**}$ (0.0102) | $0.0363^{*}$ (0.0187) |
| Debt-to-GDP ratio                 | $-0.0198^{**}$ (0.0087) | $-0.0258^{**}$ (0.0104) | $-0.0244^{***}$ (0.0030) | $-0.0095^{***}$ (0.0018) | $-0.0374^{**}$ (0.0162) |
| No. of observations               | 540               | 540                | 540                                  | 540                                      | 522                              |
| R-square                          | 0.4253            | 0.4506             | 0.3905                                |                                          | 6.47265 [0.000]          |
| Wald chi-square                   |                   |                    |                                      |                                          | 1.439.81 [0.000]          |
| Arellano–Bond test for second-order (AR2) serial correlation |                   |                    |                                      |                                          | 0.00 [1.000]          |
| Hansen test of overidentifying restrictions |                   |                    |                                      |                                          | 0.00 [1.000]          |
| Panel B: 3-year standard deviation of weather variables |                   |                    |                                      |                                          | 0.7332*** (0.0525)               |
| Fiscal budget 1-year lagged       |                   |                    |                                      |                                          | 0.5427*** (0.2688)               |
| 3-year standard deviation temperature | $-0.5958^{*}$ (0.3147) | $-0.4646^{**}$ (0.2021) | $-0.4568^{*}$ (0.2412) | $-0.3732^{**}$ (0.1711) | $-0.5427^{**}$ (0.2688)               |
| 3-year standard deviation rainfall | $-0.0148$ (0.0400) | $-0.0185$ (0.0193) | $-0.0111$ (0.0142) | $-0.0091$ (0.0123) | $-0.0544$ (0.0482)               |
| No. of observations               | 540               | 540                | 540                                  | 540                                      | 522                              |
| R-square                          | 0.4470            | 0.4210             | 0.3892                                |                                          | 3.572.79 [0.000]          |
| Wald chi-square                   |                   |                    |                                      |                                          | 1.353.43 [0.000]          |
| Arellano–Bond test for zero autocorrelation in first-differenced errors and order (2) |                   |                    |                                      |                                          | 0.51 [0.607]          |
| Sargan test of overidentifying restrictions |                   |                    |                                      |                                          | 0.00 [1.000]          |

Robust standard errors within the parentheses, $p$-values within the brackets. $^{***}$, $^{**}$ and $^{*}$ indicate significance at the 1%, 5% and 10% level.
there are three channels of the climate change impact on the government budget (Perry and Ciscar, 2016; Bachner and Bednar-Friedl, 2019; Krogstrup and Oman, 2019).

First, climate change reduces economic output and employment, reducing the income tax base, and, thus, the government revenues fall, and, second, by increasing the climate-related expenditures for disaster recovery and relief payments to households and unemployment benefits because of a reduction in output. These expenditures also include hospitalization and healthcare costs caused by heat exposure and injuries from floods and storms. Spending on social security income would increase if injuries caused by climate change and extreme weather events force people to retire earlier or if they cause a rise in disability rates. The third channel includes indirect effects, which refer to the reduction in non-climate government consumption, aiming to compensate for climate-related expenditures. But, evidence shows that the reduction in non-climate expenditures is significantly lower than climate-related expenses, reducing fiscal balance (Bachner and Bednar-Friedl, 2019). An important feature is discretionary spending and resource misallocation, which implies expenditures that could be allocated to public investments and that could increase employment, and production is diverted into climate-related expenditures (Bachner and Bednar-Friedl, 2019).

In Table 3, we report the estimates of public debt. We find a significant impact of the average temperature and no effect of rainfall on the debt-to-GDP ratio. We show that according to the FGLS, the temperature on average increases the annual debt-to-GDP ratio by 0.8%, around 1.6–1.7% based on the RE and PCSE, and ranging between 2 and 2.4% based on the FE and GMM estimates. Thus, the results show that if the average temperature increases by 1 °C, then the annual debt-to-GDP ratio can increase up to 2.4%. As we illustrate in the next section, the decreases in fiscal balance and increase in debt can be significantly higher if the countries experience an increase in temperature of over 1 °C.

There is a link between climate change, natural disasters, government budget deficits and debt. Since countries experience a fall in income tax base because of climate change, they need to increase climate-related expenditures by borrowing. If governments over-borrow to finance the fiscal balance deficit, they will experience a higher long-term interest rate, which consequently tends to slow economic growth by crowding-out private investments. Furthermore, countries that borrow and have high levels of debt-to-GDP ratio will need to repay their debt at higher interest rates. It can become even more stressful if governments borrow from abroad and have to repay the debt in foreign currency, usually in US dollars, like the MENA region countries (Daher Alshammary et al., 2020). This can deteriorate during economic recessions, such as the COVID-19 pandemic, where fiscal balance deficits in the MENA region widened to 10.1 percent of GDP in 2020 from 3.8 percent of GDP in 2019, and government debt increased from 47.6 to 56.4 percent of GDP in the same period (IMF, 2021).

To measure the inter-annual temperature and rainfall volatility, we compute the standard deviation of these variables using monthly average values over 3 years. The concluding remarks about the direction and significance of the estimated coefficients stay the same. The only difference is that the size is higher, and the interpretation differs. If we consider the OLS-FE model in panel B of Table 2, the estimated coefficient becomes −0.5958. This finding implies that an increase in the standard deviation of temperature will reduce the fiscal balance by around 0.59 percent. Thus, the effects can be considerably higher in periods of extreme heatwaves, droughts and low levels of rainfall and precipitation, where the deviation in the temperature is higher.

Similarly, in panel B of Table 3, a standard deviation increase from the average temperature may increase the debt by 13 percent of the GDP. The results show that higher
Table 3  Estimates for regression (1) and debt-to-GDP ratio

|                                | Fixed effects (FE) | Random effects (RE) | Panel-corrected standard errors (PCSE) | Feasible generalized least squares (FGLS) | Generalized method of moments (GMM) |
|--------------------------------|--------------------|---------------------|---------------------------------------|-------------------------------------------|--------------------------------------|
| **Panel A: Average weather variables** |                    |                     |                                       |                                            |                                      |
| Debt-to-GDP ratio lagged        |                    |                     |                                       |                                            | 0.9418*** (0.2185)                   |
| Average temperature            | 2.0454*** (0.9293) | 1.6943** (0.7178)   | 1.6211*** (0.5639)                    | 0.8786* (0.5278)                          | 2.4421*** (1.1566)                   |
| Average rainfall               | −0.0357 (0.1282)   | −0.1319 (0.1270)    | −0.0522 (0.1047)                      | −0.0601 (0.0714)                         | −0.6359 (0.9249)                     |
| Real GDP growth rate           | −0.1006** (0.0434) | −0.0945** (0.0472)  | −0.0842** (0.0417)                    | −0.1606*** (0.0503)                      | −0.2385* (0.1240)                    |
| Unemployment rate              | 2.4469*** (0.9601) | 2.2094*** (0.9078)  | 1.6512*** (0.4479)                    | 1.7857*** (0.3399)                       | 1.8131* (1.0577)                     |
| Inflation rate                 | −0.1105 (0.2531)   | −0.1334 (0.2551)    | −0.1094 (0.0927)                      | −0.0132 (0.0593)                         | 0.2606 (0.6571)                      |
| Polity IV                      | −0.1064 (0.3123)   | −0.0570 (0.3204)    | −0.0513 (0.0482)                      | −0.0701* (0.0380)                        | −1.2111* (0.6605)                    |
| No. of observations            | 540                | 540                 | 540                                   | 540                                       | 522                                  |
| R-square                       | 0.2167             | 0.2157              | 0.3885                                |                                            |                                      |
| Wald chi-square                |                    |                     | 3.830.92 [0.000]                      | 128.24 [0.000]                           | 45.46196.000                        |
| Arellano–Bond test for second-order (AR2) serial correlation |                    |                     |                                       |                                            | −0.57 [0.568]                        |
| Hansen test of overidentifying restrictions |                    |                     |                                       |                                            | 0.00 [1.000]                        |
| **Panel B: 3-year standard deviation of weather variables** |                    |                     |                                       |                                            |                                      |
| Debt-to-GDP ratio lagged       |                    |                     |                                       |                                            | 0.9164*** (0.2126)                   |
| 3-year standard deviation temp | 13.306** (5.9865)  | 12.267** (5.9317)   | 7.3239* (3.9896)                      | 7.8342** (3.8693)                        | 8.1680** (3.8035)                    |
| 3-year standard deviation rain | −1.8444 (1.4403)   | −1.3953 (1.1753)    | −1.2182 (1.0693)                      | −1.0931 (0.8274)                         | −2.2297 (1.8665)                     |
| No. of observations            | 540                | 540                 | 540                                   | 540                                       | 522                                  |
| R-square                       | 0.2403             | 0.2392              | 0.3870                                |                                            |                                      |
| Wald chi-square                |                    |                     | 7.612.54 [0.000]                      | 125.06 [0.000]                           | 49.383.19 [0.000]                    |
| Arellano–Bond test for zero autocorrelation in first-differenced errors and order (2) |                    |                     |                                       |                                            | −0.69 [0.492]                        |
| Sargan test of overidentifying restrictions |                    |                     |                                       |                                            | 0.00 [1.000]                        |

Robust standard errors within the parentheses, p-values within the brackets. ***, ** and * indicate significance at the 1%, 5% and 10% level
volatility in temperature has a higher adverse effect on fiscal balance and debt. This reflects the impact of extreme weather events and natural disasters caused by climate change in the short-run period, such as heatwaves, droughts, wildfires, floods, sand and dust storms in the MENA region countries (World Bank, 2019; Al-Sarihi et al., 2021). Approximately 58 percent of monthly average temperature observations exceed the average value of 21 °C. In this set, the average temperature is 28 °C. The average temperature in the remaining 42 percent of the observations is 15 °C. As we present in the online supplementary material, this finding is close to the threshold in temperature at 18–20 °C, where higher values than this point lead to decreases in the government budget and increases in debt.

Additional robustness checks to support our findings are located in the online supplementary material, where we perform various regressions as robustness checks. In particular, we consider the quadratic terms of average temperature and rainfall, the maximum temperature and the standardized precipitation index (SPI) as alternative drought measures. In particular, SPI can capture the level of droughts in different timescales, wherein the short term is related to soil moisture, while on long-term scales, it relates to reservoir storage and groundwater. Furthermore, SPI can be used as a measure of comparison across regions and countries with different climates. Following Acevedo Mejia et al. (2018), we also include the quadratic terms of average temperature as an additional robustness check. More specifically, we aim to investigate whether economies experience growth and an increase in fiscal balance at low temperatures and decreases at high-temperature levels. Another measure of climate change is the maximum temperature, used to capture extreme changes in weather and, in particular, heat waves, which are common in the MENA region countries. With the robustness checks, we find that the coefficients on the rainfall variables are always negative, though not always statistically significantly different from zero. This provides additional evidence that the rainfall and precipitation levels in the MENA region are low and have no impact on the fiscal balance and public debt.

Next, in Table 4, we report various first-difference ARDL models. The first model is a dynamic fixed effect (DFE), the second model is the pooled mean group (PMG), and the last model is the dynamic common correlated effects and cross-sectional (DCCE-CS) ARDL with one lag. While there are various tests to investigate the order of the lag, such as the Akaike and Bayesian Information criteria, we should note that one lag is sufficient based on those tests and according to the number of observations. We use two types of climate change that we have employed in the results of Tables 2–3: the average temperature and rainfall and the 3-year standard deviation. We should recall that we explore the changes in climate change variables.

We prefer the DCCE-CS ARDL since the PMG and the DFE-ARDL models do not account for the problem of cross-sectional dependence. To recall, even though we accept the null hypothesis of the cross-sectional independence, according to the Pesaran CD test and the results in Table A1 in the Appendix, we derive our conclusions based on the Breusch and Pagan LM Test. This is because it fits for panel data with $T$ larger than $N$, in contrast to the Pesaran CD test, which is more proper in panel data with $N > T$. Moreover, the PMG estimator constrains the long-run elasticities to be equal across all panels, leading to efficient and consistent estimates if these restrictions hold. However, it is common to reject the hypothesis of slope homogeneity, which we believe is our case too. In all cases, we find a negative and significant error correction term implying that there is a convergence in the long-run period.

We observe that the short-run relationship of the average temperature ranges between 0.24 and 0.30 in the DFE and DCCE-CS-ARDL models, while it is estimated at 0.18 using the PMG model. The long-run relationship in the DFE is 0.35, significantly higher to the
PMG at 0.27 and the DCCE-CS-ARDL at 0.31. Thus, an increase in the average temperature by 1 °C decreases the fiscal balance by around 0.3 percent. As was expected, the short-run and long-run relationships are higher when we consider the 3-year standard deviation ranging between 0.6 and 0.74 based on the estimates in Table 4. Thus, according to the DCCE-CS-ARDL estimates, if the temperature increases by one standard deviation, the fiscal balance will decline by 0.65 in the short-run period and by 0.68 in the long run.

4.2 Impact of climate change on fiscal balance and public debt 2020–2099

The second part of the analysis incorporates the projection of the fiscal balance and public debt in 2020–2099 because of changes in average temperature and rainfall under four scenarios. As we have mentioned in the previous section, the scenario RCP2.6 refers to the low GHG emissions scenario, and RCP4.5 and RCP6.0 refer to the low-medium and medium–high scenarios, respectively. RCP8.5 is the high GHG emissions scenario, where a climate change policy is absent. We have discussed in detail what every scenario entails. We have applied a simple panel vector autoregression (VAR) model using 1-year lagged variables, and obtaining the projections of the average temperature and rainfall by the World Bank, we have estimated the potential impact on fiscal balance and public debt. We should notice that climate change projections are changes in temperature and rainfall. For instance, the average projected change in temperature in 2020–2039 under the scenario RCP2.6 is 1 °C, and the average rainfall in the same period and under the same scenario is 0.235. Thus, these values present changes.

In Table 5, we observe that in the low emissions scenario, MENA region countries will experience a reduction in fiscal balance by 1.7% on average in 2020–2039, almost 2.4% reduction in 2040–2079 and a 2.2% reduction in 2080–2099, while the average increase in the debt-to-GDP ratio will be around 6% in the period 2020–2099. The two medium emissions scenarios, RCP4.5 and RCP6.5, illustrate similar projections for 2020–2079. The average reduction in the fiscal balance ranges between 1.9 and 3.8%, but it increases at −3.9% under the scenario RCP4.5 and −4.9% under the RCP6.0 scenario. Similarly, the projected average increase in the debt-to-GDP ratio will range between 5.3 and 12.8% in 2020–2079, with an average increase in debt at 15% under the medium-to-high scenario RCP6.0 in 2080–2099, and around 12% under the low-to-medium scenario RCP4.5. The decline in the fiscal balance under the high GHG emissions is roughly doubled compared to the low and low-to-medium scenarios, with values ranging between 2.3% in 2020–2039, 5% in 2040–2079 and about 7.3% in 2080–2099.

It is remarkable to highlight that in the case of the low scenario, we see an increase in the fiscal deficit from 1.69 in 2020–2039 to 2.370% in 2040–2059, but we note a reduction of 2.344% in 2060–2079 and 2.192% in 2080–2099. We present a similar pattern in the public debt, with an increase from 5.052 in 2020–2039 to 6.873% in 2040–2059, and then we observe a reduction at 6.522% in 2060–2079 and 6.248% in 2080–2099. This finding shows that even though climate change can be permanent, if changes in the temperature stay below the target of 1 °C, then the growth in public debt will spread the financial efforts and deficits over time, resulting in a reduction in the average fiscal deficit and debt-to-GDP ratio.

Several countries in the MENA region are already taking initiatives to advance their global climate pledges and transition to a low-carbon, climate-resilient economy (Sieghart and Betre, 2018). Recognizing that climate change poses an urgent threat to its mission, the World Bank Group has pledged to address the issue and collaborate with
Table 4 First differences ARDL for regressions (2)-(3) and fiscal balance using average and 3-year standard deviation of temperature and rainfall

|                          | Dynamic fixed effects (DFE) | Pooled mean group (PMG) | Dynamic common correlated effects and cross-sectional DCCE-CS-ARDL | Dynamic fixed effects (DFE) | Pooled mean group (PMG) | Dynamic common correlated effects and cross-sectional DCCE-CS-ARDL |
|--------------------------|-----------------------------|-------------------------|-------------------------------------------------|-----------------------------|-------------------------|-------------------------------------------------|
|                          |                            |                         |                                                |                            |                         |                                                |
| Panel A: Long-run relationships |                            |                         |                                                |                            |                         |                                                |
| Average temperature      | −0.3509** (0.1383)         | −0.2667*** (0.0468)     | −0.3120*** (0.1183)                              |                            |                         |                                                |
| Average rainfall         | −0.0175 (0.0384)           | −0.0283 (0.0467)        | −0.0166 (0.0193)                                |                            |                         | −0.6186* (0.3366)                                 |
| 3-year standard deviation temperature |                |                         |                                                |                            |                         | −0.5868* (0.3348)                                 |
| 3-year standard deviation rainfall |                |                         |                                                |                            |                         | −0.6775** (0.3267)                                |
| Panel B: Short-run relationships |                            |                         |                                                |                            |                         |                                                |
| Error correction term    | −0.2865*** (0.0318)        | −0.3631*** (0.0371)     | −0.2166*** (0.0688)                              | −0.2942*** (0.0322)        | −0.3702*** (0.0469)                              | −0.2503*** (0.0619)                                |
| First-difference average temperature | −0.2415** (0.1119)        | −0.1836** (0.0759)      | −0.2996*** (0.1027)                              |                            |                         |                                                |
| First-difference average rainfall | −0.0169*** (0.0074)        | −0.0133 (0.0161)        | −0.0161 (0.0176)                                |                            |                         |                                                |
| First-difference 3-year standard deviation temperature |                |                         |                                                |                            |                         | −0.7326* (0.3872)                                 |
| First-difference 3-year standard deviation rainfall |                |                         |                                                |                            |                         | −0.6005** (0.2742)                                 |
| No. of observations      | 522                        | 522                     | 504                                            | 522                        | 522                     | 504                                            |

Standard errors within the parentheses, p-values within the brackets. ***, ** and * indicate significance at the 1%, 5% and 10% level.
countries to achieve their climate goals. World Bank has laid out concrete actions intending to scale up climate action. Actions aim to integrate climate change across its operations and collaborate more closely with others to implement new and innovative solutions through collective action and partnerships, such as the Climate Change Action Plan adoption (World Bank, 2016).

5 Conclusions

In this study, we attempted to explore the impact of climate change on fiscal balance and public debt in the MENA region countries. The findings show a significant negative effect of temperature on government budget and public debt. In the long term, a 1 °C increase in the average temperature reduces fiscal balance by 0.30 percent. We find a quadratic relationship between fiscal balance and temperature in the short-run period. At low temperatures, an increase in temperature boosts the government budget, but at high temperatures, an increase in temperature decreases fiscal balance. We estimate the threshold average annual temperature at around 18–20 °C. Similarly, in the long-run period, the average temperature increases the debt-to-GDP ratio by 1.87 percent. In the short-run period, increases in temperature reduce the debt-to-GDP ratio up to 21–22 °C, whereas after this point, the debt increases.

Then we used the temperature and rainfall projected values in 2020–2099 to examine the effect on fiscal balance and debt. We find in the high emissions scenario that the fiscal balance will decline between 2.35 and 7.29%. The respective values for public debt range between 6.5 and 18.5%. Based on the two medium emissions scenarios, the fiscal balance will decline between 1.8 and 4%. The values for public debt range between 5 and 15%.

Yet, this paper is not without drawbacks. The quantification of the fiscal impacts of climate change is still underdeveloped. Future research studies should investigate the link between economic loss and the public budget. A breakdown of the damage costs would aid in determining the impact on the various components of budget balances. Also, we have not explored the direct and indirect budgetary effects of climate change. Furthermore, the standard deviation of the weather conditions relied on annual data, even though we took the monthly averages. Thus, we have used the inter-annual standard deviation and not

| Period        | RCP2.6 scenario | RCP4.5 scenario | RCP6.0 scenario | RCP8.5 scenario |
|---------------|-----------------|-----------------|-----------------|-----------------|
| Panel A: Fiscal balance                  |
| 2020–2039     | −1.696          | −1.858          | −1.942          | −2.354          |
| 2040–2059     | −2.370          | −2.670          | −2.953          | −4.039          |
| 2060–2079     | −2.343          | −3.537          | −3.822          | −6.094          |
| 2080–2099     | −2.192          | −3.944          | −4.989          | −7.290          |
| Panel B: Debt-to-GDP ratio              |
| 2020–2039     | 5.052           | 5.312           | 5.512           | 6.449           |
| 2040–2059     | 6.873           | 7.922           | 8.669           | 12.005          |
| 2060–2079     | 6.522           | 11.172          | 12.816          | 15.999          |
| 2080–2099     | 6.248           | 12.039          | 15.032          | 18.488          |
daily or monthly changes within the year. A comparison between changes in the inter- and intra-annual standard deviation could be an interesting topic for further investigation. Thus, there are still many avenues for future research.

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**Declarations**

**Ethics approval** This article does not contain any studies with human participants or animals performed by the author.

**Conflict of interest** The authors declare no competing interests.

**Informed consent** Informed consent was not sought and not required for the present study, because the analysis is based on secondary data.

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