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Whether it's weather or climate: Temperature and individual deprivation in Sub-Saharan Africa[☆]

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ABSTRACT

Sub-Saharan Africa is widely regarded as one of the world's most climate-vulnerable regions, yet large-scale evidence linking temperature exposure to individual-level welfare remains fragmented. In this paper, we provide a unified assessment of temperature exposure across multiple time horizons by linking daily, monthly, yearly, and long-run average temperature data to 168,585 geo-referenced households in 28 African countries. Our results consistently reveal a statistically robust negative association between higher temperatures and individual living standards, whether arising from short-term weather shocks or long-run climatic conditions. Quantitatively, these effects are modest, particularly once individual characteristics and local geographic conditions are accounted for. Notably, we find no substantive differences between impacts of short-term temperature and long-run climatic effects, suggesting limited past adaptation to sustained heat exposure. The fact that temperature-related welfare losses are differentially stronger among rural and agriculturally engaged households further highlights the persistent vulnerability of climate-sensitive livelihoods. Crucially, however, local infrastructural endowments emerge as an important moderating factor, significantly weakening the association between temperature exposure and individual-level deprivation. This finding points to scope for adaptation through investments in basic infrastructure and service provision.

1. Introduction

Inquiries into the economic impact of increasing temperatures have largely provided evidence of a negative overall effect (for a recent overview see Tol, 2024).[1] Notably, this average result masks considerable variability both in the magnitude and the direction of expected effects (e.g. Newell et al., 2021).[2] However, a rather consistent result across the literature is that (more severe) negative effects are anticipated for countries and regions which are hotter to begin with (e.g. Burke et al., 2015b) as well as for those that are poor (e.g. Dell et al., 2012).[3]

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[1] Further surveys of the literature are given by Dell et al. (2014), Carleton and Hsiang (2016), Howard and Sterner (2017), Nordhaus and Moffat (2017), and Tol (2018).

[2] The main sources of heterogeneity in reported results stem, among others, from the different empirical specifications, mainly the dichotomy between cross-sectional approaches identifying long-term (climatic) effects (e.g. Mendelsohn et al., 1994) and panel settings that identify shorter-term climatic fluctuations, i.e., weather shocks (see e.g. Dell et al., 2012). There are also hybrid approaches, such as regressing on non-linear specifications of temperature in a panel, or long-differences specifications recovering "medium-term" effects (Burke and Emerick, 2016). For an empirical investigation using all three approaches, see Kalkuhl and Wenz (2020). For more on these empirical caveats see Hsiang (2016) and Kolstad and Moore (2020). Other (methodological) discussions revolve around whether to employ (economic) outcomes, such as GDP, in growth or in levels (see Newell et al., 2021).

[3] Of course, many of the hottest countries on the planet are poor. However, existing evidence points to an income-independent inverted U-shaped relationship between temperature and income across the globe (Burke et al., 2015b), as well as linearly increasing negative effects of rising temperatures in poorer countries (see Letta and Tol, 2019). Sub-Saharan Africa is a particular case in point which may suffer relatively more due to progressing climate change (e.g. Lanzafame, 2014). At the same time, some regions may experience negligible or even positive effects of climate change, particularly where baseline temperatures are relatively low (see e.g. Kalkuhl et al., 2020; Cruz and Rossi-Hansberg, 2024).

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In this paper, we examine the relationship between temperatures and *individual livelihoods* in Sub-Saharan Africa, one of the hottest and poorest regions in the world. We thereby evaluate both the short-term response to weather (shocks) and the long-run equilibrium effects of high temperatures (climate change) by matching daily, monthly, yearly, and long-term average temperature data to an underutilized, geo-referenced household-level survey of 168,585 individuals sampled across 28 African countries over 16 years (Afrobarometer, 2022). The analysis complements both macro-level studies on aggregate outcomes as well as the expanding micro-level literature on climate vulnerability in highly exposed regions[4] in two important ways.

First, the Afrobarometer allows us to link finely resolved local temperature exposure to both objective and, crucially, personal assessments of individual living standards. This enables us to capture welfare-relevant dimensions of climate exposure that are often obscured in aggregate indicators or proxy-based measures such as nighttime lights, particularly in largely informal economies, where economic activity is imperfectly captured by conventional statistics. Additionally, compared to other commonly employed micro-level datasets,[5] the Afrobarometer provides detailed information on *local* conditions, including governance, service delivery, or related infrastructural characteristics. This richness enables a multidimensional assessment that captures both material and institutional deprivation. Importantly, it allows us to directly measure and condition on *local* institutional and infrastructural capacities that are central to how households absorb and governments respond to both short-run weather shocks and longer-run climatic change. *Second*, by directly comparing short-run weather shocks and long-run climatic conditions within a unified empirical framework across a large number of households over different countries, we examine how transient temperature fluctuations relate to longer-run equilibrium effects. By simultaneously conditioning on finely gridded local first- and second-nature geographic characteristics, and individual-level covariates, our approach also speaks to concerns that existing estimates of long-run climate effects may partly reflect confounding of such characteristics (see e.g. Hsiang, 2016; Kolstad and Moore, 2020). Leveraging the rich objective and self-reported measures and conditioning on factors described above, our analysis complements the existing evidence base in an important way and is particularly informative for interpreting climate damage estimates and adaptation policy design.

Our analysis yields three main insights. First, higher temperatures are consistently associated with increased individual deprivation, regardless of whether temperature exposure is measured using short-term weather shocks or long-run climatic conditions. Notably, we find no substantive attenuation in the magnitude of temperature effects when moving from short-run to long-run horizons. In fact, long-run climatic coefficients frequently exceed those of short-term weather shocks. This lack of attenuation from short- to long-run exposure suggests limited past adaptation to sustained heat, particularly in settings where livelihoods remain closely tied to climate-sensitive activities. Second, while the established relationships are statistically robust, their quantitative magnitude is modest. For instance, a one degree Celsius increase in two-week pre-interview temperatures above the sample mean (23.1 °C) raises individual deprivation by approximately 0.5 percent. While statistically robust, these effects are modest when compared to other structural determinants of economic development. For example, within the same estimating framework and sample, the estimated poverty-reducing effect of completing primary education is more than twenty-five times larger at 12.6 percent. This suggests that while temperature is a statistically significant stressor, it may not display the dominant driver of individual deprivation in the context of Sub-Saharan Africa. Third, vulnerability to temperature exposure is highly uneven and strongly mediated by local conditions. Welfare losses are concentrated among rural households and individuals engaged in agriculture. At the same time, local infrastructural endowments emerge as a powerful buffering factor: access to basic services substantially weakens the temperature-deprivation relationship and is itself strongly associated with lower deprivation levels. In several specifications, plausible improvements in infrastructure reduce the implied welfare impact of higher temperatures to near-zero magnitudes, and have quantitative importance that exceed those of temperature alone, pointing to meaningful scope for adaptation. Importantly, these findings are robust across a wide range of specifications and measurement choices, including alternative temperature measures capturing tail sensitivity, restrictive fixed-effects structures and standard error clustering, as well as a quasi-experimental event-study extension.

The remaining sections of the paper are organized as follows: Section 2 discusses the theoretical channels via which short-term temperature and long-term climatic conditions are expected to influence individual deprivation in Sub Saharan Africa. Section 3 introduces the data used and the empirical strategy. Section 4 presents and discusses our findings. Section 5 provides concluding remarks.

2. Economic impact of climate in Sub-Saharan Africa

A close examination of the hypothesized channels through which temperature is suggested to affect individual livelihoods underscores Sub-Saharan Africa's vulnerability to current climatic conditions as well as future climate change (for recent surveys on the empirical support of channels see Carleton and Hsiang, 2016; Acevedo et al., 2020)

For one, given the direct connection between climatic conditions and land use, rising temperatures have been suggested to negatively impact agricultural yield (see Carter et al. (2018) for an overview of this channel), and there is evidence for sizeable negative effects in Sub-Saharan Africa (see e.g. Schlenker and Lobell, 2010). Relatedly, an additional stressor of the continent is the continuous prevalence of pests and diseases, which further burdens agricultural output (e.g. Alsan, 2015). Given that over 50 percent of Africans still depend on agriculture for their livelihoods (World Bank, 2022), rising temperatures are likely to translate into individual deprivation through this channel. This concern is amplified by the fact that evidence on successful adaptation remains mixed, even in highly developed countries (e.g. Schlenker and Roberts, 2009; Hornbeck, 2012; Burke and Emerick, 2016).[6]

Second, the increased heat stress associated with rising temperatures may directly affect both labor productivity and labor supply: There is evidence pointing to shortened work hours, effort, and intensity due to high temperatures, both in high- and low-income settings

[4] Studies have investigated outcomes such as household wealth (Park et al., 2018), physical health (Hyland and Russ, 2019), education (Wilde et al., 2017), fertility (Thiede and Strube, 2020), child health (Thiede and Strube, 2020; Baker and Anttila-Hughes, 2020; Rajkhowa and Chakrabarti, 2024; Flückiger and Ludwig, 2022), child marriage (Tsaneva, 2020), labor market outcomes (Henderson et al., 2017; Brookes Gray et al., 2023), occupations (De Sario et al., 2023), migration (Helbling et al., 2021), mental health (Adhvaryu et al., 2024), political trust and conflict (Vestby, 2019; Aboyadana and Alfano, 2021; Ahlerup et al., 2024), intimate partner violence (Sekhri and Storeygard, 2014; Díaz and Saldarriaga, 2023), and household deprivation (Bukari and Aluko, 2023).

[5] Most micro-level studies examining the effects of climate on individual outcomes rely on the Demographic and Health Surveys (DHS). The Afrobarometer has so far been used only sparingly, with existing applications largely examining climate change literacy (Helbling et al., 2021) or political trust and democratic attitudes (Aboyadana and Alfano, 2021; Cerkez, 2024; Ahlerup et al., 2024). To our knowledge, only Bukari and Aluko (2023) study living standards using a single round of the Afrobarometer, focusing on droughts and floods. We exploit six survey rounds to jointly assess short-run weather shocks and long-run climatic effects across countries.

[6] While improved irrigation and water storage can mitigate the impacts of droughts or flooding (e.g. Duflo and Pande, 2007), much of the adverse effect on agricultural productivity is attributable to higher temperatures (see e.g. Schlenker and Roberts, 2009; Hornbeck, 2012; Burke and Emerick, 2016).

as well as in labor- and capital-intensive firms (e.g. Zhang et al., 2018; Letta and Tol, 2019; Somanathan et al., 2015). These effects are particularly pronounced among workers engaged in outdoor occupations (e.g. Graff Zivin and Neidell, 2014). What is more, temperatures can affect human capital formation, as (lifelong) learning outcomes might be attenuated in warmer environments (e.g. Park, 2022). As such, weather conditions have been directly connected to lowered earnings (e.g. Fishman et al., 2019), with depressed (prenatal) child health (e.g. Deschênes and Moretti, 2009; Kudamatsu et al., 2012; Flückiger and Ludwig, 2022) or educational attainment (e.g. Maccini and Yang, 2009) as potential mediating channels.

Relatedly, climatic conditions may also affect physical health outcomes (for an overview see Deschênes, 2014; Heal and Park, 2016). Next to directly affecting mortality (e.g. Deschênes and Greenstone, 2011; Barreca et al., 2016), increased temperatures and weather shocks have been associated with increased morbidity and may spur the prevalence of infectious diseases (e.g. Wu et al., 2016). For instance, increased weather variability has spurred epidemic malaria periods in East Africa (e.g. Zhou et al., 2004). At the same time, rising temperatures may also attenuate the spread of certain disease vectors, contributing to the potential decline of yellow fever in parts of Africa (e.g. Wu et al., 2016), while enabling malaria to expand into new geographic areas (e.g. Peterson, 2009; Béguin et al., 2011). Temperature-related dynamics were also observed during the COVID-19 pandemic, where warmer conditions were associated with reduced transmission rates (e.g. Wang et al., 2020; Prata et al., 2020). Given that endemic diseases have historically plagued economic development in Africa, both directly through reduced labor productivity (e.g. Gallup et al., 1999) and indirectly via persistent institutional legacies of colonial rule (e.g. Acemoglu et al., 2001), this channel further underscores the importance of analyzing the relationship between climatic conditions and individual livelihoods using granular data that captures local contexts and endowments.

A third channel through which effects of climate change may be particularly pronounced in Africa pertains to conflict and political stability. In Africa, evidence for this channel is particularly vast, as variations in rainfall (Miguel et al., 2004), temperatures (Burke et al., 2009), as well as droughts (Couttenier and Soubeyran, 2014) have all been shown to spur the incidence of conflict (for an overview of this literature see Burke et al., 2009, 2015a). Moreover, increased temperature has been associated with political instability in the form of coups (Dell et al., 2012), but may also strengthen the demand for democracy given the subsequent economic struggle and plights (e.g. Burke and Leigh, 2010; Brückner and Ciccone, 2011). One particular way to cope with increased prevalence of conflict is out-migration, which can place additional strains on (local) economic capacity (Dreher et al., 2011; Abel et al., 2019). More broadly, climate change has been linked to migration decisions (Bohra-Mishra et al., 2014; Beine and Parsons, 2015), particularly in Africa, where increasing temperatures have been argued to move highly skilled individuals abroad or put additional strain on the already growing urban areas (Barrios et al., 2006; Henderson et al., 2014). At the same time, the poorest individuals may be unable to migrate due to binding budget constraints (see e.g. Cattaneo and Peri, 2016), potentially exacerbating vulnerability and further straining individual livelihoods.

Given these aspects, it is no surprise that Sub-Saharan African economies have long been regarded as countries with one of the highest levels of vulnerability to climate change (see e.g. Brooks et al., 2005; Eriksen and Kelly, 2007). In addition, potential adaptation to higher temperatures is likely far more challenging in regions burdened with economic, fiscal, and institutional difficulties compared to relatively richer regions (see e.g. Mortreux and Barnett, 2017; Cinner et al., 2018; Siders, 2019). Hence, investigating the potential impact of an unfavorable climate on individual Sub-Saharan livelihoods is relevant to understanding what future temperature increases may imply for the continent.

Of course, temperature need not be destiny, and structural provisions can help mitigate some of the adverse effects of increasing temperatures. For instance, infrastructural endowments such as dams, irrigation systems, roads, sewage networks, clinics, banks, and electricity grids have been linked to the attenuation of both short- and long-term impacts of climate variability and change (see e.g. Duflo and Pande, 2007; Burgess et al., 2017). Also, institutions have been shown to influence the extent to which relief is provided in droughts (Besley and Burgess, 2002) or natural disasters (see e.g. Kahn, 2005), and may safeguard against high temperature more generally (see e.g. Meierrieks and Stadelmann, 2024). While these factors have been shown to have the potential to moderate the effects of climate change at the macroeconomic level, assessing their role in mitigating individual deprivation is essential to determine whether these aggregate patterns extend to the micro level, specifically, whether infrastructure and institutions help shield individuals from the adverse consequences of climate change.

3. Data and empirical strategy

We combine geo-referenced household-level survey data from the Afrobarometer (Afrobarometer, 2022) with high-resolution climate data to construct indicators of individual living standards and temperature exposure. Specifically, we match each survey observation to daily weather data from the CPC Global Unified Temperature dataset produced by the Climate Prediction Center of the National Oceanic and Atmospheric Administration (NOAA) (CPC, 2024), as well as to long-term average climatic conditions (1970–2000) from WorldClim version 2.1 (Fick and Hijmans, 2017).

3.1. Afrobarometer data

Our primary unit of observation is the individual, respectively, their corresponding household-level information, drawn from six rounds of the repeated cross-sectional Afrobarometer survey.[7] The Afrobarometer is a nationally representative, cross-sectional, household-level survey of voting-age citizens (aged 18 and above) that has been conducted at regular intervals since its introduction in 1999. Our analysis draws on a total of 28 countries sampled in six survey rounds: 2002–2004, 2005–2006, 2008–2009, 2011–2013, 2014–2015, and 2016–2018 for which all variables required to examine the relationship between temperature and individual deprivation are consistently available.[8] Depending on the year, each country sample consists of 1200 or 2400 respondent cases, with an average of eight individuals surveyed within a unique enumeration area (EA) which reflects unique latitude-longitude combinations.[9] Table A.8 of the Appendix reports the baseline sample of countries and observations from which the main analytical sample is constructed.

The Afrobarometer includes detailed individual- and household-level questions on living conditions and a wide range of socio-demographic characteristics. In addition, it provides rich information on respondents' perceptions and attitudes toward the economy, institutions, democracy, and governance. As our main outcome of interest,

[7] For further details on survey design and methodology, see https://www.afrobarometer.org/surveys-and-methods/.

[8] We exclude the first survey round due to inconsistencies in questionnaire design and variable coding relative to subsequent rounds.

[9] In the earlier rounds (2–6), respondents' geographic coordinates were not directly recorded during data collection and coordinates were attached by post-survey geo-coding (BenYishay et al., 2017). Following the granularity scale, precision is measured as an integer ranging from 1 to 8 (coordinates referring to the country). The latter categories (5–8) account for approximately 1 percent of the respondents. However, from round 7 onwards, all respondent locations were marked via GPS tracking by the interviewer, putting them entirely into category 1. We conduct robustness checks on our results by dropping all entries with precision code of 4 or higher.

we consider individual-, respectively, household deprivation as the capability to meet the basic needs for food, water, medical care, as well as cash income. The corresponding survey questions read: *"Over the past year, how often, if ever, have you or a member of your household gone without any of the following essentials ['Enough food to eat', 'Medicines or medical treatment', 'Enough clean water for home use', and 'A cash income']"*.[10] The possible answers range from *never*, *just once or twice*, *several times*, *many times* and *always*, which we code in this precise order using integer values from zero to four. We look at each of these deprivation indicators separately as well as jointly. For the joint analysis, we construct a *deprivation index* by taking the simple average of each individual's response to the four questions, such that the *deprivation index* has a continuous range from zero to four.

In contrast to much of the literature, we employ self-reported measures of economic deprivation. Next to the complementarity to the existing literature, using self-reported measures is advantageous for at least three further reasons: First, aggregate reported income and macroeconomic indicators such as GDP often fail to accurately capture individual well-being, particularly in largely informal economies and in non-democratic settings where incentives to misreport or manipulate official statistics have been documented (see e.g. Martínez, 2022). Second, proxy measures of development such as nighttime light intensity are not individual-specific and may perform poorly in weakly electrified, low-density rural or predominantly agricultural areas (e.g. Gibson et al., 2021; Bickenbach et al., 2016). They are also prone to interpretation issues due to heterogeneous elasticities across contexts (Bluhm and McCord, 2022). Third, with our data, we are able to combine our individual deprivation measures with rich information on local institutions and infrastructural provision to explore conditioning factors as well as potential (coping) mechanisms.

3.2. Data on climatic conditions

We rely on two complementary climate data sources to assign both short-run weather variation and long-run climatic temperature exposure to households surveyed in the Afrobarometer.[11] First, to capture short-run weather variation, we use daily surface air temperatures from the CPC Global Unified Temperature dataset produced by the Climate Prediction Center of the National Oceanic and Atmospheric Administration (NOAA) (CPC, 2024). These data are provided on a 0.5° latitude-longitude grid (approximately 50 km at the equator) and include daily minimum and maximum temperatures from 1979 onward.[12] Second, to assess the longer-run equilibrium effects of climate, we use long-term average monthly temperatures for the period 1970–2000 from WorldClim version 2.1 (Fick and Hijmans, 2017). These data are available at a spatial resolution of 30 arc seconds (approximately 1 km at the equator) and are matched to each enumeration area and interview month.[13]

Using the available data, we construct five complementary temperature measures to examine the short- as well as long-run relationship between temperatures and individual living standards. To capture short-run weather shocks, we use the (i) *daily average temperature*, i.e. the average of the maximum and minimum on the day of the interview, and the (ii) *two-week average temperature*, constructed as the 14-day average of daily average temperatures preceding the interview.[14] In addition, we aggregate the daily average temperature in the month as well as year of the respective interview to construct (iii) *interview-month average temperature* and (iv) *interview-year average temperature*. Lastly, to estimate long-run equilibrium effects, we employ (v) *long-term average monthly temperature* (1970–2000) at the enumeration-area level, which captures persistent climatic conditions and allow us to assess how sustained temperature differences, rather than transient weather fluctuations, relate to individual deprivation outcomes.

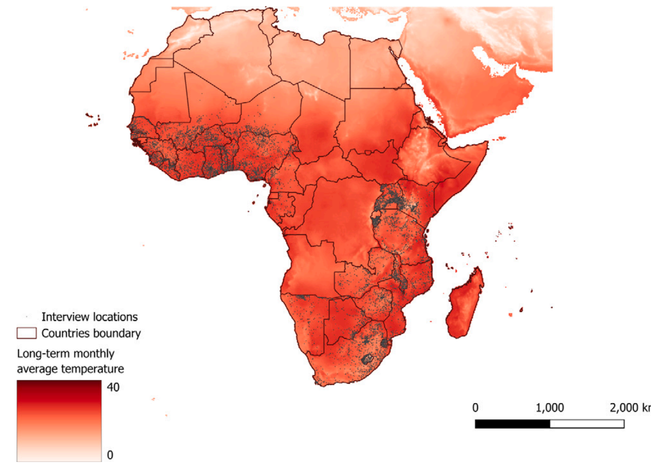

Fig. 1. Long-term monthly average temperatures depicted together with Afrobarometer enumeration areas.

Fig. 1 depicts the variation in *long-term average monthly temperature* together with the unique sample enumeration areas of the Afrobarometer across our survey time frame.

3.3. Covariates

To isolate the effect of temperatures from other, potentially correlated, influences on individual deprivation, we draw on distinct covariates at the individual- as well as the enumeration-area level. We include age, gender, and educational level as basic socio-demographic controls, add information on the household's locality (i.e. urban vs. rural), and control for further physical geographic characteristics shown to influence (local) economic output. To do this, we proceed in the same fashion as with the temperature data and attach information on first-nature features of the respondent's EA including precipitation (Fick and Hijmans, 2017), elevation (Farr et al., 2007), ruggedness (Nunn and Puga, 2012), malaria ecology (Sachs et al., 2004), land suitability (Ramankutty et al., 2002), and the number of growing days (FAO and IIASA, 2019). To account for relevant second-nature features of the enumeration area, we add proximity to the coast (Wild and Stadelmann, 2022), as well as distance to major rivers and lakes (Lehner and Döll, 2004; Henderson et al., 2018; Earth, 2019). Adding these covariates allows us to report conditional associations between temperature measures and individual deprivation.

[10] We exclude cooking fuel as an indicator in the main analysis because simple fuel-type measures exhibit limited construct validity and perform inconsistently across settings. Prior work shows that single indicators often fail to capture affordability, sufficiency, and multiple-fuel use, and may therefore provide an incomplete and context-dependent measure of deprivation (see e.g. Al Kez et al., 2024; Li et al., 2014). For completeness, we show results including cooking fuel in our index in Table A.7 in the Appendix.

[11] Specifically, we assign the temperature value of a grid cell to all households located within an enumeration area falling inside that cell.

[12] See https://psl.noaa.gov/data/gridded/data.cpc.globaltemp.html for further details.

[13] WorldClim provides high-resolution global climate surfaces based on historical observations. See https://www.worldclim.org/data/worldclim21.html for further information.

[14] Although the recall period for our primary outcome variable spans 12 months, we deliberately include higher-frequency temperature measures to reflect the well-documented likelihood of recall bias, whereby respondents place greater weight on recent or current conditions when evaluating their living standards. More generally, behavioral reactions to higher temperatures have been documented in the recent literature (Gavresi et al., 2024; Stadelmann et al., 2025).

In total, our main sample comprises 168,585 individuals and households surveyed across 14,186 unique enumeration areas (EAs) in 28 Sub-Saharan African countries over a 16-year period. Table A.1 in the Appendix reports summary statistics for this sample, covering all key variables just introduced.

3.4. Empirical strategy

We estimate the following regression specification to establish the baseline relationship between temperatures and individual deprivation in our data:

$$Y_{i,c,ym} = \beta_0 + \beta_1 T_i + \beta_k \boldsymbol{X}_i + \theta_{cym} + \epsilon_{i,c,ym} \tag{1}$$

$Y_{i,c,ym}$ denotes the deprivation measure of individual i living in country c and sampled in the month and year combination ym. T_i represents the respective temperature measure assigned to individual i based on their enumeration area. $\boldsymbol{X}_i$ is a vector of k individual- as well as local geographic control variables introduced in Section 3.3. For our main estimates, we include multiplicative country–year–month fixed effects θ_{cym}, such that β_1 is identified by within-country differences in temperatures and living standards at a specific point in time, i.e. within a specific survey sampling year-month combination. $\epsilon_{i,c,ym}$ is the idiosyncratic error term and we compute standard errors clustered at the survey enumeration area level.[15]

The interpretation of β_1 depends on the temperature measure employed. When using the high-frequency measures (e.g. daily or two-week averages), β_1 captures the effect of short-run weather shocks on individual living standards, identified by contemporaneous variation (within month) in temperature within a country, holding fixed relevant institutional, seasonal, or macroeconomic conditions through the fixed-effects structure. Importantly, the inclusion of country–year–month fixed effects mitigates concerns about endogenous short-run adjustment to transitory temperature variation, such as migration, conflict, or other behavioral responses, as any such responses would need to occur within the same month (and across enumeration areas) to bias the estimate. In contrast, when using the long-term average temperature measure, β_1 reflects long-run equilibrium effects associated with climate change, respectively, climatic conditions. In this case, identification stems from (repeated) cross-sectional comparisons of individuals living in persistently warmer versus cooler locations within the same country and survey period. These estimates thereby inherently incorporate and reflect any past adaptation or equilibrium sorting in response to sustained temperature differences. By conditioning on a rich set of individual characteristics as well as finely gridded first- and second-nature geographic and institutional features, we are able to account for such potential past adaptation to the extent that it operates through these channels (Hsiang, 2016; Kolstad and Moore, 2020).

Analyzing the relationship between temperature and economic development measured by individual deprivation from this perspective offers several advantages and thereby complements the existing literature. First, it enables a direct comparison of short-run weather shocks and long-run climatic conditions at the individual level, moving beyond aggregate region- or country-level outcomes. Second, with respect to long-run equilibrium effects, our approach mitigates concerns about unobserved local- or individual-level confounders that often complicate inference in more aggregated cross-sectional analyses (see e.g. Kolstad and Moore, 2020). Finally, the richness of the data allows us to assess the role of *local* moderating mechanisms, such as institutional quality and infrastructural endowments, that may have attenuated the adverse effects of long-term temperature exposure or buffered individuals against short-term weather shocks.

[15] In robustness tests, we also compute standard errors clustered at the GADM1 region-year level and apply Conley standard errors to allow for spatial dependence.

4. Results and discussion

4.1. Baseline results

Table 1 presents the baseline results produced by estimating Eq. (1), where the four individual deprivation indicators and the joint deprivation index are used as dependent variables in turn, including multiplicative country–year–month fixed effects but without yet conditioning on control variables. The results consistently reveal a negative relationship between ambient temperature and individual livelihoods, i.e. positive and statistically significant associations between short- as well as long-run measures of temperatures and individual deprivation across food, water, medicine, and cash income.

Concerning the shorter-term impact of temperatures, we observe that an increase in the daily average temperature (row 1) by one degree Celsius is associated with an increase in food deprivation (column 1) by 0.022 units. Compared to the mean food deprivation in the sample (1.12), this represents a 1.96 percent increase, and going from the 1st to the 3rd quartile of daily interview temperatures in the sample suggests a 14.89 [= (0.022 * (27.07–19.49)) / 1.12] percent increase. Similarly, a one degree Celsius increase in the interview-year average temperature is associated with an increase in food and cash income deprivation by 4.7 percent and 2.1 percent, respectively. Considering the long-run equilibrium effect (row 5), the deprivation index increases by 2.7 percent for each one degree Celsius increase in long-term monthly temperature.

The fact that short-term and long-term measures of temperature do not vary substantially in their estimated effects signals a lack of adjustment to past climate, whether through migration, changes in production, or other adaptive responses. This emphasizes the potential hurdles of agriculturally based economies in Sub-Saharan Africa to adapt to temperatures (e.g. Schlenker and Roberts, 2009; Hornbeck, 2012; Burke and Emerick, 2016). At the same time, the largest coefficients associated with average temperatures in the interview-year (row 4) may reflect more persistent within-year climatic stress, such as prolonged droughts or seasonally sustained agricultural shortfalls. These plausibly exert stronger impacts on household welfare than short-lived temperature fluctuations (daily or two-week) or (known) long-run average climatic conditions alone.

4.2. Relevance of covariates

Table 2 examines the sensitivity of the baseline results to the inclusion of individual- and location-specific control variables. For this analysis, we focus exclusively on the composite deprivation index as the outcome. We proceed in a stepwise fashion, assessing the robustness of the main coefficient of interest, β_1, while successively adding several dimensions of relevant controls. Given that some of the controls added (e.g. education, occupation) may be channels via which temperature influences individual development outcomes, this approach has the added benefit of providing a quantitative indication of such potential mediating processes. For instance, if lower temperatures lessen the incentive to invest in education, e.g. because of a location's comparative advantage in agriculture, controlling for schooling captures the potential effect of temperature running via this (theoretical) channel.

First, we introduce basic demographic characteristics, encompassing respondents' sex and age (incl. age squared). Thereafter, we sequentially add individuals' educational level, their employment status and the household's location type, i.e. an urban dummy.[16] We augment the

[16] Educational level is defined by the highest level of education an individual has attained. We code the level of education into five ascending levels: no education, informal education, basic education, secondary education, and tertiary education. The employment status has been categorized into two groups: "unemployed" for individuals who answered "no" to the employment status question, regardless of whether they are actively seeking employment or not, and "employed" for those who are either full-time or part-time employed.

Table 1
The effect of temperature on individual deprivation.

Temperature measure (*all in* °C)	Food deprivation {0,4}	Water deprivation {0,4}	Medical care deprivation {0,4}	Cash-income deprivation {0,4}	Deprivation index [0,4]
	(1)	(2)	(3)	(4)	(5)
Daily average temperature	0.022***	0.019***	0.020***	0.021***	0.020***
	(0.002)	(0.003)	(0.002)	(0.002)	(0.002)
Two-week average temperature	0.039***	0.036***	0.034***	0.037***	0.037***
	(0.003)	(0.004)	(0.003)	(0.003)	(0.002)
Interview-month average temperature	0.041***	0.038***	0.037***	0.039***	0.039***
	(0.003)	(0.004)	(0.003)	(0.003)	(0.003)
Interview-year average temperature	0.053***	0.047***	0.044***	0.045***	0.047***
	(0.003)	(0.005)	(0.003)	(0.003)	(0.003)
Long-term average monthly temperature	0.043***	0.041***	0.036***	0.032***	0.038***
	(0.003)	(0.004)	(0.003)	(0.003)	(0.003)
Controls	No	No	No	No	No
Country-Year-Month FEs	Yes	Yes	Yes	Yes	Yes
Observations	168,350	168,380	167,896	167,892	168,585
R-squared	0.088	0.066	0.104	0.152	0.138
Mean of deprivation measure	1.117	1.177	1.242	2.123	1.414

Results in each cell are produced by a separate regression via Eq. (1) using the main sample of countries included in survey rounds 2 through 7 of the Afrobarometer. Each row reports the coefficient estimates of different temperature measures on the respective deprivation indicators in columns (1) through (5). Positive values indicate higher levels of deprivation. The deprivation index is computed by averaging individuals' responses to food, water, medical care and cash income indicators. Temperature is measured in degrees Celsius and coefficients thereby report changes in the respective deprivation outcome associated with a 1 °C increase in temperature. Reported R-squared values are taken from the specification using daily average temperature, respectively. The standard errors reported are clustered at the survey enumeration area level and reported in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

model with further first- and second-nature geographic characteristics introduced in 3.3 and thereby include features such as precipitation, elevation, ruggedness, malaria ecology, land suitability, and the number of growing days. We then add second-nature features such as proximity to the coast, major rivers and lakes in a second step.

As shown in Table 2, temperature continues to be a statistically significant predictor of individual deprivation, although the magnitude of the effect diminishes when accounting for relevant covariates.[17] Notably, the coefficient estimates start to decrease more starkly as the level of education is added and they drop further as geographic controls are included. For instance, in column (1), an increase in the daily temperature by one degree Celsius increases deprivation by 0.020 units when there are no covariates; the coefficient drops to 0.016 units when we consider socio-demographics and finally diminishes a magnitude of 0.003 units, i.e. fairly close to zero, when we account for all first- and second-nature factors measured. Given the large number of observations, the results still show statistically relevant associations, except in the case of daily average temperatures once accounting for geographic factors (see column 1). This was to be expected given the high variability in daily temperatures and the potential mismatch with the actual exposure window.

Importantly, while the quantitative association between temperature and individual deprivation has already been relatively modest in specifications without additional controls (Table 1), the estimates in Table 2 show a notable attenuation of temperature coefficients, β_1, once individual and geographic covariates are introduced. This attenuation is particularly pronounced following the inclusion of education and first-nature geographic characteristics. Given that these factors have been proposed as potential mediators through which temperature may influence deprivation outcomes, their attenuation effect on β_1 is not surprising. For example, persistent temperature conditions may shape local comparative advantages, potentially reducing incentives to invest in education in predominantly agricultural environments. Then conditioning on schooling removes any portion of the temperature–deprivation relationship operating through this channel. Consistent with this interpretation, in our full specification (row g), completing primary education is associated with a reduction in deprivation of 12.6 percent, while completing secondary education is associated with a reduction of 24.7 percent (see Table A.2). This highlights the central role of education as an independent structural determinant of economic development. At the same time, the provision of schooling represents a co-determinant that is, at least in part, amenable to policy intervention. Similarly, temperature may affect agricultural productivity by influencing land suitability, particularly in settings without irrigation or crop rotation, such that controlling for land suitability captures part of this indirect pathway. Nevertheless, the remaining statistical significance and magnitude of the temperature coefficients suggest that the mediating role of these factors is limited in quantitative terms and does not fully account for the observed relationship between temperature and individual deprivation.

4.3. Robustness tests and extensions

We conduct an array of additional robustness tests on our baseline results, which are summarized in Table A.3 of the Appendix and include all social-demographic and geographic controls. We thereby (a) include survey sampling weights, adjusted for varying sample size proportions across countries and year; (b) construct an alternative version of our deprivation index by employing principal component analysis; (c.1) allow for spatial correlation via Conley standard errors (Conley, 1999) and (c.2) compute standard errors cluster at the region-year level. We also adjust the fixed-effects structure by replacing country–year–month fixed effects with (d.1) country–year fixed effects, (d.2) country–year–month-day fixed effects, (d.3) additive region and year fixed effects, (d.4) multiplicative region–year–month fixed effects as well as (d.5) multiplicative ethnicity-year-month fixed effects.[18] We also check for sample precision and outliers by (e) dropping respondents with a geo-precision score greater than 3 (precision is measured on an integer scale of 1–8, decreasing in precision) and (f) dropping South Africa from the sample. The pattern of these robustness tests aligns with the most conservative specification including all controls (Table 2, line g).

[17] Table A.2 in the Appendix provides coefficient estimates of all the included control variables individually.

[18] To proxy ethnicity, we harmonize Afrobarometer ethnicity and language responses across survey rounds and map them to standardized three-letter ISO 639–3 language codes from Ethnologue. Using the full ethnolinguistic family tree provided by Ethnologue and implemented via the LEDA (Linking Ethnic Data from Africa) framework (Müller-Crepon et al., 2022), this procedure yields consistent ethnolinguistic groupings across countries and survey waves.

Table 2
Temperature and individual deprivation – Relevance of included covariates.

Included covariates	Dependent variable: Deprivation index [0,4]				
	Temperature measure (*all in* °C)				
	Daily average (1)	Two-week average (2)	Interview-month average (3)	Interview-year average (4)	Long-term average monthly (5)
a = No controls	0.020***	0.037***	0.039***	0.047***	0.038***
	(0.002)	(0.002)	(0.003)	(0.003)	(0.003)
b = a + Demographic controls	0.020***	0.036***	0.038***	0.046***	0.038***
	(0.002)	(0.002)	(0.003)	(0.003)	(0.003)
c = b + Level of education	0.016***	0.029***	0.031***	0.039***	0.034***
	(0.002)	(0.002)	(0.002)	(0.003)	(0.002)
d = c + Employment status	0.016***	0.028***	0.030***	0.038***	0.033***
	(0.002)	(0.002)	(0.002)	(0.003)	(0.002)
e = d + Urban dummy	0.014***	0.025***	0.027***	0.033***	0.032***
	(0.002)	(0.002)	(0.002)	(0.003)	(0.002)
f = e + First-nature geography	0.003**	0.008***	0.009***	0.016***	0.032***
	(0.002)	(0.002)	(0.003)	(0.004)	(0.004)
g = f + Second-nature geography	0.003	0.007***	0.008***	0.015***	0.038***
	(0.002)	(0.002)	(0.003)	(0.004)	(0.005)
Country-Year-Month FEs	Yes	Yes	Yes	Yes	Yes
Observations	165,037	165,037	165,037	165,037	165,037
R-squared	0.205	0.205	0.205	0.205	0.205

Results in each cell are produced by a separate regression via Eq. (1) using the main sample of countries included in survey rounds 2 through 7 of the Afrobarometer. The dependent variable is an index computed by averaging individuals' responses to food, water, medical care and cash income indicators. Positive values indicate higher levels of deprivation. Temperature is measured in degrees Celsius and coefficients thereby report changes in the respective deprivation outcome associated with a 1 °C increase in temperature. Reported R-squared values and observations are from the specification including all covariates (row g), respectively. The standard errors reported are clustered at the survey enumeration area level and reported in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Coefficients, except for short-run temperature increases, are statistically significant but small in magnitude. Two exceptions arise when applying multiplicative region–year–month and ethnicity–year–month fixed effects. These demanding fixed effects structures closely track individuals' geographic location and absorb much of the residual local temperature variation, such that shorter-run temperature fluctuations no longer emerge as statistically significant. Despite this, long-term average monthly climatic conditions remain robustly associated with individual deprivation even in this demanding setting.

To further assess the sensitivity of our results to alternative representations of temperature exposure, we conduct additional robustness checks in Table A.4 that allow us to capture tail sensitivity as well as extreme and cumulative heat impacts. Specifically, we consider the (a) maximum daily temperature instead of the daily average; (b) diurnal temperature range; (c) seasonal temperature variation[19]; (d) cumulative heat degree-days[20]; as well as varying time periods of (e) pre-interview heat exposure.[21] In addition, we estimate a spline regression across various temperature bins to explicitly test for masked tail effects in Table A.5.

To advance a potential causal interpretation of our short-run temperature estimates, we extend Eq. (1) and include additional two-week temperature intervals preceding the interview as pre-trends, as well as corresponding post-interview intervals as placebo checks. Specifically, we include separate indicator variables capturing two-week average temperatures exceeding 30 °C during the periods 0–2 weeks prior to the interview, 2–4 weeks prior, 4–6 weeks prior, and 6–8 weeks prior, as well as analogous post-interview intervals up to eight weeks after the interview.[22] This specification essentially corresponds to an event-study framework that exploits quasi-exogenous variation in short-term temperature fluctuation. The results are reported in Figure A.1. The absence of significant post-interview effects, combined with the strongest effects and statistical precision in the two-week interval immediately preceding the interview, supports the interpretation that our baseline short-run temperature estimates capture plausibly causal effects rather than spurious correlations driven by persistent spatial or seasonal confounding. Similar to the spline regressions in Table A.5, we use the event-study framework to also examine potential non-linearities in the effect of short-run temperature exposure. We thereby replace the two-week >30 °C indicator prior to the interview with a set of distinct temperature bins, holding everything else fixed. The resulting estimates are reported graphically in Figure A.2.

Overall, the additional investigations in this section do not alter the main conclusions and interpretations drawn earlier. However, two noteworthy patterns emerge. First, short-term measures that capture extreme or cumulative heat exposure, such as daily maximum temperatures, heat degree days, or brief episodes of extreme heat above 30 °C, are associated with larger increases in deprivation than average short-run temperature measures. However, even these tail-sensitive indicators do not yield coefficient sizes that systematically exceed the magnitude of the estimated long-run equilibrium climate effects (Table A.4). This finding reinforces the absence of a declining gradient from short- to long-run impacts and provides little evidence of meaningful adaptation to sustained heat exposure. Second, the spline specifications in Table A.5 suggest the presence of non-linearities in equilibrium climate effects. In particular, increases in long-run average temperatures above roughly 20–30 °C are associated with markedly stronger increases in deprivation, whereas temperature changes at lower levels are associated with smaller, or in some cases offsetting, effects. Importantly, allowing for such non-linearities does not overturn the broader conclusion that long-run climatic exposure dominates short-run weather variation in shaping individual deprivation outcomes. Finally, seasonal temperature variation emerges as a salient dimension of climate exposure. Greater within-year temperature variability is associated with higher deprivation across all outcome dimensions, suggesting that instability in climatic conditions, rather than mean temperatures alone, may constitute a distinct burden on individual welfare.

[19] Seasonal temperature variation is defined as the difference in average daily temperatures across winter (Dec–Feb), spring (Mar–May), summer (Jun–Aug), and autumn (Sep–Nov) at each location.

[20] Heat degree-days capture cumulative heat exposure by summing daily temperature exceedance above 30 °C in the year of the interview.

[21] Pre-interview heat exposure is defined as an indicator for whether average temperatures exceeded 30 °C within a defined pre-interview time window.

[22] Rather than using continuous temperature bins, we adopt a threshold-based heat-wave specification to reduce the multicollinearity generated by correlation in adjacent temperature averages.

Table 3
Potential channels linking temperature to individual deprivation.

Temperature measure	Most important problem facing country		
(*all in* °C)	Drought {0,1} (1)	Health {0,1} (2)	Conflict {0,1} (3)
(1) Daily average temperature	0.002***	0.001**	−0.0002
	(0.0002)	(0.0005)	(0.0005)
(2) Two-week average temperature	0.004***	0.003***	−0.00004
	(0.0004)	(0.001)	(0.001)
(3) Interview-month average temperature	0.004***	0.003***	−0.0004
	(0.0004)	(0.001)	(0.001)
(4) Interview-year average temperature	0.005***	0.003***	0.0002
	(0.0004)	(0.001)	(0.001)
(5) Long-term average monthly temperature	0.003***	0.003***	0.001
	(0.0004)	(0.001)	(0.001)
Controls	No	No	No
Country–Year–Month FEs	Yes	Yes	Yes
Observation	168,581	168,581	168,581

Results in each column are produced by a separate regression via Eq. (1) using the main sample of countries included in survey rounds 2 through 7 of the Afrobarometer. Coefficients report changes in the probability that respondents identify a given issue as the most important problem facing their country per 1 °C increase in temperature. Standard errors are clustered at the survey enumeration area level and reported in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

4.4. Mechanisms and heterogeneity

Given the pronounced heterogeneity in estimated climate impacts across regions and populations documented in the literature (see, e.g. Dell et al., 2012; Burke et al., 2015b; Cruz and Rossi-Hansberg, 2024), the negative average association between temperature and individual deprivation documented in our results need not hold uniformly across individuals in our sample. Even within Sub-Saharan Africa, responses may differ systematically depending on production and consumption patterns, local biophysical conditions, or broader regional characteristics.

To explore such potential conditionalities within our setting, we proceed in two steps. First, we probe the salience of three potential mechanisms introduced in Section 2 by exploiting the Afrobarometer perceptions module and analyzing the relationship between temperature exposure and respondents' answers to the question: *"In your opinion, what are the most important problems facing this country that the government should address?"*. This module allows us to assess the salience of three key channels by examining whether temperature exposure affects the likelihood that respondents identify (i) *"Drought"*, capturing a climate-related stressor that directly affects agricultural livelihoods; (ii) *"Health/Sickness & Disease"*, reflecting potential direct physiological effects and indirect health consequences of temperature exposure; and (iii) *"Crime & Security/War / Civil War"*, indicative of conflict or competition over scarce resources. The results, presented in Table 3, indicate that higher temperatures increase the salience of drought- and health-related concerns, while we find no systematic association between temperature exposure and perceptions of conflict-related issues.

Second, we then assess whether the previously estimated temperature effects vary systematically across individuals with such exposure and vulnerability profiles. Specifically, we conduct subsample analyses along two salient dimensions. First, we stratify by occupational category, contrasting individuals engaged in agricultural activities with those employed in non-agricultural sectors, where reliance on climate-sensitive production is plausibly weaker. Second, we distinguish between urban and rural respondents, capturing systematic differences in economic structure, infrastructure, and exposure to climatic conditions. These heterogeneity results on the deprivation index are reported in Table 4. Consistent with results in Table 3, the link between temperatures and individual deprivation appears to be markedly more pronounced among individuals engaged in agricultural-related activities, reiterating decreased agricultural productivity as one of the main channels through which temperatures exert their negative impact in Africa. Similarly, the effects seem (tentatively) more pronounced for individuals living in rural- compared to urban areas.[23]

Together, these findings corroborate evidence from the existing literature that both rural areas and agricultural households are subject to relatively higher losses in the face of rising temperatures. Interestingly, short-term weather shocks do not seem to beget stronger losses than the long-run equilibrium effect for agricultural livelihoods. This may in part reflect limited adaptive capacities discussed before (e.g. Schlenker and Roberts, 2009; Hornbeck, 2012; Burke and Emerick, 2016). Consistent with this pattern, an additional heterogeneity test across agro-ecological zones (Table A.6) shows that temperature increases are most strongly associated with higher deprivation in tropical forest and tropical grassland regions, where livelihoods are predominantly based on heat-sensitive, rain-fed agriculture. In contrast, no significant coefficient estimates for temperature are detected in montane grasslands, plausibly because of the natural thermal buffering provided by higher elevations.[24]

4.5. Evidence on coping and adaptation strategies

Importantly, exposure to high temperatures need not inevitably translate into adverse welfare outcomes and specific structural provisions may contribute to mitigating the negative consequences of climatic stress. In particular, physical investments into the local infrastructure, such as dams, irrigation systems, transport networks, electricity, health facilities (see e.g. Duflo and Pande, 2007; Burgess et al., 2017), as well as the presence of responsive and effective institutions (see e.g. Besley and Burgess, 2002; Kahn, 2005; Meierrieks and Stadelmann, 2024) have been shown to reduce vulnerability to both short-run weather shocks and longer-run climatic change.

To examine whether institutional quality and infrastructural endowments moderate the relationship between temperature and individual deprivation, we extend regression Eq. (1) by interacting T_i with a measure of *local* institutional quality and an index capturing the availability of basic infrastructure at a respondent's survey locale. Specifically, we proxy local infrastructural endowments by exploiting information on the availability of essential services within a respondent's enumeration

[23] Importantly, the evidence on a differentially stronger effect on rural (agrarian) households also holds in a sub-sample of agrarian households (urban regions). Results can be obtained from the authors.

[24] While temperate grasslands are historically the most agriculturally suitable, our lack of statistically significant findings there likely stems from limited geographic coverage and reduced sample size within this specific zone.

Table 4
Heterogeneous effects by occupation and locality.

Temperature measure	Deprivation index [0,4]			
	Employment sector		Locality type	
	Agricultural activity (1)	Non-agricultural activity (2)	Rural (3)	Urban (4)
Daily average temperature	0.007**	−0.0003	0.003	−0.001
	(0.004)	(0.002)	(0.002)	(0.003)
Two-week average temperature	0.016***	0.003	0.008**	0.005
	(0.006)	(0.004)	(0.003)	(0.005)
Interview-month average temperature	0.020***	0.007	0.009**	0.006
	(0.006)	(0.004)	(0.004)	(0.005)
Interview-year average temperature	0.029***	0.012**	0.015***	0.012*
	(0.008)	(0.005)	(0.005)	(0.007)
Long-term average monthly temperature	0.039***	0.037***	0.033***	0.026***
	(0.010)	(0.007)	(0.006)	(0.008)
Socio-demographic controls	Yes	Yes	Yes	Yes
Geographic controls	Yes	Yes	Yes	Yes
Country-Year-Month FEs	Yes	Yes	Yes	Yes
Observations	32,054	48,467	56,615	108,422
Mean of deprivation measure	1.644	1.206	1.114	1.570

Results in each cell are obtained from separate regressions estimated via Eq. (1) on sub-samples defined by the occupational sector, respectively, their locality type, using Afrobarometer survey rounds 2 through 7. The dependent variable is a deprivation index constructed by averaging individuals' responses to food, water, medical care, and cash income indicators. Positive values indicate higher levels of deprivation. Temperature is measured in degrees Celsius and coefficients thereby report changes in the respective deprivation outcome associated with a 1 °C increase in temperature. The standard errors reported are clustered at the survey enumeration area level and reported in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

area, including access to an electricity grid, pipe-borne water, sewerage, health clinics, and schools, as documented in the Afrobarometer. Based on these binary indicators, we construct a continuous *local infrastructure* variable ranging from 0 to 1, with higher values indicating a greater presence of local infrastructural endowments. To capture local institutional quality, we follow Mitton (2016) and construct an index based on respondents' answers to 21 survey questions covering individuals' trust in key public institutions (including local government, the police, and courts), experiences with corruption and bribery, as well as assessments of administrative effectiveness and law enforcement.[25] A full list of the underlying survey items used to construct this institutional quality index is provided in Table A.9. The resultant continuous *institutional quality* variable ranges from 0 to 4, with lower values indicating worse judgments of (local) institutional quality.

Table 5 presents the results of our moderation analysis. To aid interpretation, both the temperature variables and the respective moderators have been centered at the mean value in the sample. Generally, temperature remains positively associated with individual deprivation at average levels of institutional quality and infrastructural endowment. While institutional quality on its own is linked to substantially lower deprivation, its interaction with temperature does not provide evidence of a robust moderating effect. In quantitative terms, institutional quality itself, however, substantially exceeds temperature's impact.

In contrast, infrastructural endowments play a pronounced role along two dimensions. First, infrastructure is independently associated with markedly lower levels of deprivation, with scale-adjusted coefficient magnitudes similar to those of institutional quality. Second, infrastructure also emerges as a statistically significant moderator, substantially attenuating the adverse effect of higher temperatures on individual deprivation. For example, increasing an enumeration area's infrastructural endowment from the sample mean (0.528), corresponding to access to roughly half of the basic services considered, to full service provision reduces the estimated effect of a one degree Celsius increase in long-term monthly average temperature (interview-year average temperature) from 0.013 (0.037) to just 0.005 (0.028), respectively. Importantly, when looking at the direct effect of the same infrastructural improvement independent of temperatures, deprivation is reduced by 13.8%. A comparable exercise for institutional quality yields even larger reduction of 21.6%.

These findings underscore the central role of basic service provision in alleviating potential welfare shortfalls due to rising temperatures. They also suggest that improvements in local infrastructural and institutional capacity can deliver substantial welfare gains. Importantly, these gains are largely independent of temperature exposure and they exceed the direct impacts of rising temperatures.

5. Conclusion

Sub-Saharan Africa is widely viewed as one of the regions most exposed to the adverse consequences of climate change. High baseline temperatures, a strong reliance on agriculture, subsistence farming, and institutional as well infrastructural constraints have been expected to amplify the expected welfare losses and limit adaptive capacity.

In this paper, we provide novel evidence on how both short-term weather shocks and long-run climatic conditions relate to individual living standards across Sub-Saharan Africa. Exploiting an underutilized geo-referenced household dataset covering 28 countries, we show that increases in temperature, both in the form of transitory weather shocks and persistent climatic conditions, are negatively and robustly associated with individual well-being, as reflected in higher self-reported deprivation in access to food, water, medical care, and cash income.

Three findings stand out: *First*, we find no substantive differences between short-term weather shocks and long-run equilibrium effects. This absence of a declining gradient from short- to long-run temperature impacts casts doubt on adaptation to sustained heat exposure and reinforces earlier evidence of potentially limited adaptive capacity in agricultural production (see Schlenker and Roberts, 2009; Hornbeck, 2012; Burke and Emerick, 2016). This result is particularly relevant given that we confirm rural and agriculturally engaged households as relatively more vulnerable to rising temperatures than the rest of the population.

Second, while the estimated relationships between different temperature measures and individual deprivation are mostly statistically robust across alternative specifications and sample refinements, the

[25] For instance, respondents are asked if they had to pay the bribe to avoid taxes or avoid going to court, and the responses are ordered ranging from "not at all" to "very likely". Other questions such as corruption of public officials have ordered responses from "none" to "all of them".

Table 5
The moderating role of *local* institutions and infrastructure.

Variable (s)	Deprivation Index [0,4]				
	Daily average temp. (1)	Two-week average temp. (2)	Interview- month average temp. (3)	Interview- year average temp. (4)	Long-term monthly average temp. (5)
Panel (a): Local institutions					
Temperature measure (*in* °C)	0.003	0.008***	0.009***	0.015***	0.036***
	(0.002)	(0.003)	(0.003)	(0.004)	(0.005)
Institutional quality [0,4]	−0.169***	−0.169***	−0.169***	−0.170***	−0.169***
	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)
Temperature × Institutional quality	−0.003*	0.001	0.001	0.003***	0.003**
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Observations	164,758	164,758	164,758	164,758	164,758
R-squared	0.215	0.215	0.215	0.215	0.216
Panel (b): Local infrastructure					
Temperature measure (*in* °C)	0.002	0.006**	0.007**	0.013***	0.037***
	(0.002)	(0.003)	(0.003)	(0.004)	(0.005)
Local infrastructure [0,1]	−0.413***	−0.414***	−0.414***	−0.413***	−0.412***
	(0.015)	(0.015)	(0.015)	(0.015)	(0.015)
Temperature × Local infrastructure	−0.003	−0.012***	−0.013***	−0.018***	−0.019***
	(0.003)	(0.002)	(0.002)	(0.003)	(0.003)
Observations	163,874	163,874	163,874	163,874	163,874
R-squared	0.213	0.213	0.213	0.214	0.214
Socio-demographic controls	Yes	Yes	Yes	Yes	Yes
Geographic controls	Yes	Yes	Yes	Yes	Yes
Country-Year-Month FEs	Yes	Yes	Yes	Yes	Yes

Results in each column and panel are produced by a separate regression via Eq. (1) using the main sample of countries included in survey rounds 2 through 7 of the Afrobarometer. The dependent variable is an index computed by averaging individuals' responses to food, water, medical care and cash income indicators. Positive values indicate higher deprivation. To aid interpretation, the indicators *institutional quality* and *local infrastructure* as well as temperature are centered at their respective mean values. Temperature is measured in degrees Celsius and coefficients thereby report changes in the respective deprivation outcome associated with a 1 °C increase in temperature. The standard errors reported are clustered at the survey enumeration area level and reported in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

quantitative magnitude of temperature effects on individual deprivation remains modest, particularly relative to other structural determinants of economic development. For instance, a one degree Celsius increase in long-run average monthly temperature raises deprivation across our four dimensions by at most 2.7 percent relative to the sample mean, whereas completing primary education is associated with a reduction of about 12.6 percent and completing secondary education with a reduction of roughly 24.7 percent. These comparisons suggest that, while temperature is a statistically relevant correlate of individual deprivation, its quantitative importance is modest relative to more proximate and policy-amenable determinants such as human capital accumulation, infrastructure investment, and institutional quality.

Third, our analysis highlights the central role of local conditions in shaping vulnerability to climatic stress. In particular, infrastructural endowments emerge as a powerful buffering mechanism: access to basic services is strongly associated with lower deprivation and systematically attenuates the estimated temperature–deprivation relationship. In several specifications, plausible improvements in local infrastructure reduce the implied welfare impact of higher temperatures to near-zero magnitudes. Beyond their moderating role, infrastructural endowments exert a substantial direct effect on individual deprivation. Quantitatively, increasing an enumeration area's infrastructural endowment from the sample mean, corresponding to access to roughly half of the basic services considered, to full service coverage is associated with a 13.8 percent reduction in the deprivation index. The same exercise using the estimated coefficient on the institutions variable leads to reductions in deprivation of 21.6 percent. This sizable effect underscores the central role of basic service provision in alleviating welfare shortfalls and suggests that improvements in local infrastructure can deliver substantial welfare gains independent of, and potentially exceeding, the direct impact of temperatures. Unlike temperature, these infrastructure and institutions can be affected through interventions at the local, regional, and national levels, offering more direct levers to mitigate deprivation.

Taken together, our findings suggest that, in the Sub-Saharan African context, the potential welfare consequences of rising temperatures may be modest and could be critically shaped by local conditions that are, to a meaningful extent, amenable to policy intervention. This points to the potential for adaptation through incremental improvements in local conditions to meaningfully attenuate the welfare impacts of climate change in Sub-Saharan Africa, even if such measures cannot fully offset broader climatic trends.

CRediT authorship contribution statement

Josephine Baako-Amponsah: Writing – review & editing, Writing – original draft, Investigation, Formal analysis, Data curation. **David Stadelmann:** Writing – review & editing, Writing – original draft, Validation, Conceptualization. **Frederik Wild:** Writing – review & editing, Writing – original draft, Validation, Investigation, Conceptualization.

Appendix A. Supplementary data

Supplementary material related to this article can be found online at https://doi.org/10.1016/j.eneco.2026.109363.

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