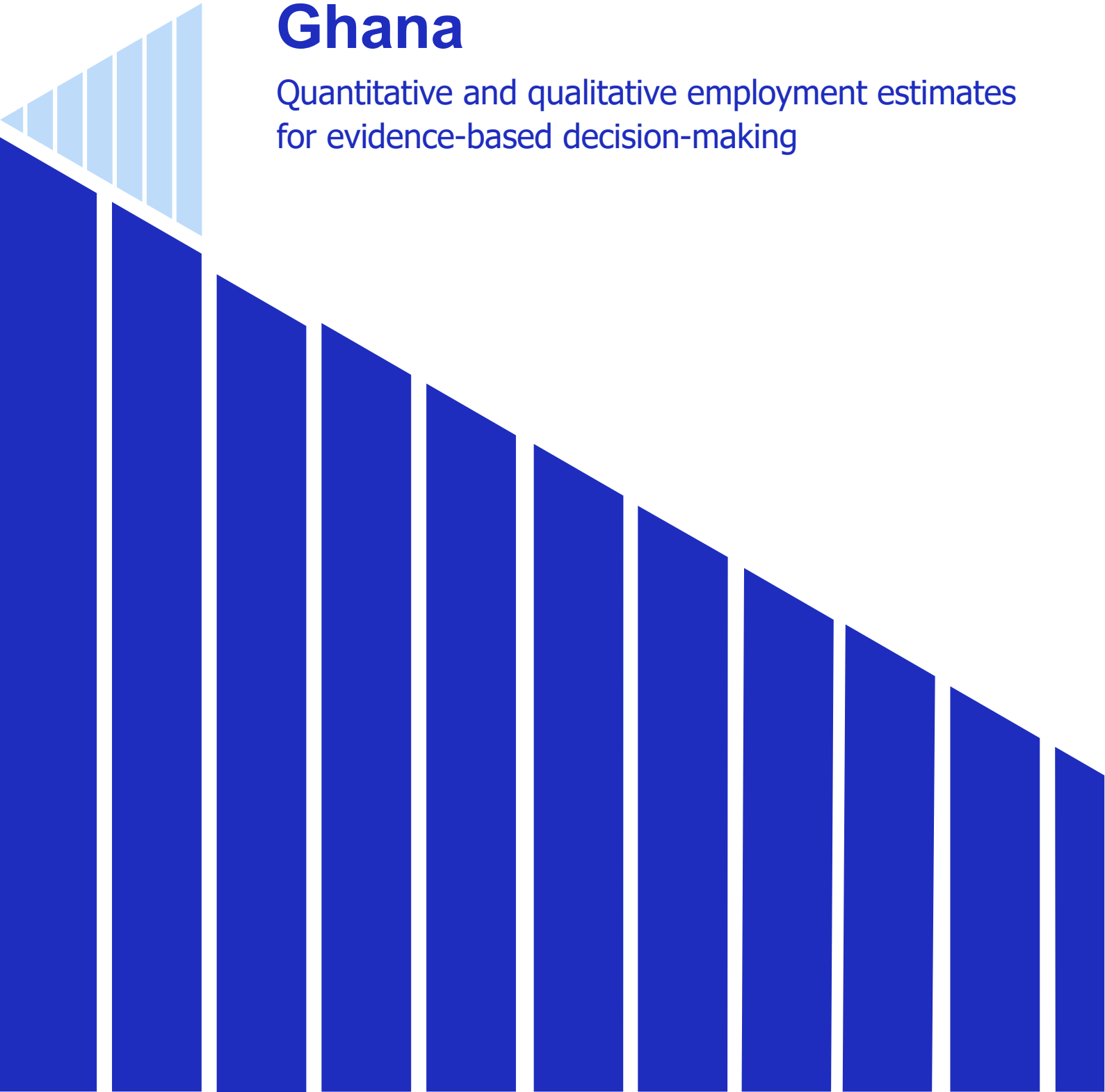
International Labour Organization

Impacts of heat stress on jobs and productivity in Ghana

Quantitative and qualitative employment estimates for evidence-based decision-making



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These studies are authored by Andreas D. Flouris, Leonidas G. Ioannou and Konstantinos Mantzios.

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1. Background

In 2015, the ILO Guidelines for a just transition towards environmentally sustainable economies and societies for all were adopted. The preamble of the Paris Agreement on climate change, also adopted in 2015, underscores close links between climate action, sustainable development and a just transition, with Parties to the Agreement "taking into account the imperatives of a just transition of the workforce and the creation of decent work and quality jobs in accordance with nationally defined development priorities". In 2023, the International Labour Conference adopted the Resolution concerning a just transition towards environmentally sustainable economies and societies for all, which endorsed the ILO Just Transition Guidelines as the central reference for policymaking and a basis for action. Ideally, any climate change policy process [such as the Nationally Determined Contributions (NDC), National Adaptation Plans (NAPs) or the Long-Term Low Emission Development Strategies (LT-LEDS)] should be informed by an assessment of the employment impacts—both positive and negative—as well as an indication of the measures that will be taken to ensure a just transition for workers and enterprises drawing on the ILO Just Transition Guidelines and the 2023 ILC Resolution. Against this backdrop, it is crucial to evaluate how environment and climate policies affect job creation or destruction (particularly for women and youth), income distribution, skills development, and overall economic growth. Providing quantitative and qualitative employment estimates for evidence-based decision-making is essential for maximizing positive and mitigating or buffering negative social and employment outcomes.

Heat stress, exacerbated by rising global temperatures and more frequent heatwaves, poses a significant challenge to occupational safety and health (OSH). According to a recent report published by the International Labour Organization (ILO),[1] excessive heat impacts more than 70% of the global workforce, exposing over 2.41 billion workers annually to hazardous conditions. The consequences are profound, with heat stress contributing to approximately 22.85 million non-fatal injuries and 18,970 fatalities every year across the world.[1] The economic and productivity costs are equally alarming, as heat stress leads to billions of productivity losses and healthcare costs annually.[1] These losses undermine economic stability and exacerbate inequalities in jobs and/or regions with high exposure to excessive heat.

1.1. Scope of this study

The available evidence underlines the urgent need to integrate heat stress mitigation strategies into national and workplace OSH frameworks. As a result of the ILO's work with the Climate Vulnerable Forum, the present study builds on the available data to provide just transition input to Climate Prosperity Plans (CPPs). It evaluates the implications of heat stress in Ghana's labour market and proposes evidence-based strategies to enhance worker safety and economic resilience. It also assesses employment data scenarios linked to green transitions and global warming, with a particular focus on productivity losses due to heat stress.

1.2. Political, economic, social, and climate overview

1.2.1. Governance and political stability

With nearly 35 million inhabitants, Ghana is the second-most populous country in West Africa. The capital and largest city is Accra, while other significant cities include Kumasi, Tamale, and Sekondi-Takoradi.

Ghana has maintained a reputation as one of Africa's stable democracies over the past decade. It stands out in West Africa for its record of peaceful, regular elections and transfers of power since the 1990s.[2] This stability has enabled consistent governance and the pursuit of long-term development policies.

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[1] ILO (2024). Heat at work: Implications for safety and health. A global review of the science, policy and practice. A. D. Flouris, M. Azzi, H. Graczyk, B. Nafradi and N. Scott. Geneva, Switzerland, International Labour Organization.
[2] U.S.A. Congressional Research Service Report (2024). Ghana: Current Issues and U.S. Relations (R47329). https://crsreports.congress.gov/product/pdf/R/R47329. Accessed: 6/12/2024.

However, governance challenges persist. Corruption remains an issue, with Ghana's Transparency International Corruption Perceptions Index scores in the low-40s (on a 0-100 scale) in recent years.[3] Economic management has been tested by fiscal imbalances – for example, a record primary deficit of about 8.8% of GDP emerged amid high spending and revenue shortfalls.[4] These fiscal stresses culminated in a severe economic crisis by 2022. The government had to seek a $3 billion IMF support program in 2023 to restore stability and debt sustainability.[5] Despite such challenges, Ghana's leadership has implemented notable policies like the Free Senior High School education program (launched in 2017) to expand social services.[6] Overall, the political environment has been stable but under pressure to improve governance and address economic grievances.

1.2.2. Economic trends and performance

Over the past decade, Ghana's economy experienced both high growth and serious macroeconomic challenges. Key economic trends include:

- **GDP Growth:** Ghana enjoyed robust GDP growth for much of the 2010s, averaging around 5-6% annually.[7] The expansion was supported by commodities (gold, cocoa, and oil) and a growing services sector. Growth receded mid-decade due to fiscal strains and low commodity prices, then rebounded to over 6% by 2017-2019 with new oil production. However, growth slowed sharply in 2020 to about 0.5% due to the COVID-19 shock and related disruptions.[8] A recovery to 5.4% growth in 2021 was followed by another slowdown to about 3.2% in 2022 amid domestic fiscal turmoil.[8]
- **Inflation:** Price stability has been a recurring problem. Inflation averaged ~14% in the decade up to 2022, well above the Sub-Saharan Africa average.[9] After peaking at about 17.5% in 2016 during a previous currency slump,[10] inflation was brought down near single digits by 2019. But in 2022, Ghana experienced a surge in inflation above 30% as the currency depreciated and global fuel and food prices spiked.[11] Inflation remained elevated also during 2023, eroding purchasing power and forcing aggressive monetary tightening.
- **Public debt:** Ghana's public debt level rose markedly over the decade. It climbed from roughly 54% of GDP in 2015 to over 80% of GDP by 2022.[12] On average, debt was about 62% of GDP during the 2010s, far above the regional average of 44%.[13] This unsustainable debt accumulation led to debt distress, as the government struggled to service obligations, prompting restructuring of both domestic and

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[3] Statista.com (2025). Corruption Perceptions Index score in Ghana from 2012 to 2023. https://www.statista.com/statistics/1287075/corruption-perception-index-in-ghana. Accessed: 6/2/2025.
[4] International Monetary Fund (2021). Ghana: Joint World Bank-IMF Debt Sustainability Analysis. https://documents1.worldbank.org/curated/en/973971632340489819/pdf/Ghana-Joint-World-Bank-IMF-Debt-Sustainability-Analysis.pdf. Accessed: 6/12/2024.
[5] Adombila M.A., Akorlie C. (2023). IMF approves $3 billion Ghana loan, with $600 million immediate payout. Reuters Foundation. https://www.reuters.com/markets/imf-executive-board-approves-ghana-3-bln-loan-facility-sources-2023-05-17. Accessed: 6/12/2024.
[6] Ghanaian Ministry of Education. Free SHS Policy. https://moe.gov.gh/free-shs-policy. Accessed: 6/12/2024.
[7] Trading Economics. Ghana GDP annual growth rate. https://tradingeconomics.com/ghana/gdp-growth-annual. Accessed: 6/12/2024.
[8] World Bank (2023). Macro poverty outlook for Ghana. Macro poverty outlook (MPO) Washington, D.C.: World Bank Group. http://documents.worldbank.org/curated/en/099907204122391347.
[9] Focus Economics (2024). Ghana Inflation (CPI, ann. var. %, aop). https://www.focus-economics.com/country-indicator/ghana/inflation. Accessed: 6/12/2024.
[10] Statista.com (2025). Ghana: Inflation rate from 1987 to 2029. https://www.statista.com/statistics/447576/inflation-rate-in-ghana. Accessed: 6/2/2025.
[11] Macrotrends LLC (2025). Ghana Inflation Rate 1965-2025. Accessed: 6/2/2025. https://www.macrotrends.net/global-metrics/countries/GHA/ghana/inflation-rate-cpi.
[12] World Economics. Ghana Debt to GDP Ratio: 82.5%. Accessed: 6/12/2024. https://www.worldeconomics.com/GrossDomesticProduct/Debt-to-GDP-Ratio/Ghana.aspx.
[13] Focus Economics. Public Debt in Ghana. https://www.focus-economics.com/country-indicator/ghana/public-debt. Accessed: 6/12/2024.

external debt in 2023. By the end of 2023, public debt stood at around 72% of GDP after some relief measures.[14]

- **Employment:** Official unemployment rates in Ghana have remained low, at only about 3-4% of the labour force in recent years.[15] This low figure shows the reality of underemployment and informal work. The vast majority of jobs are informal or vulnerable, with over 70% of employment in the informal sector in 2015.[16] Many workers, especially youth, engage in low-productivity work in agriculture or petty trade. Creating enough decent formal jobs for a growing young population remains a key economic challenge despite the low unemployment.
- **Key Industries:** Ghana's economy is driven by commodities and services. It is the world's second-largest cocoa exporter (after Côte d'Ivoire)[17] and recently became Africa's top gold producer,[18] reflecting a boom in gold mining. The discovery of oil has also made petroleum a significant industry, with oil production boosting exports and growth in the late 2010s. Beyond commodities, services (trade, banking, telecom, etc.) contribute over half of GDP, while agriculture still employs a large share of workers. This narrow commodity base makes Ghana's economy vulnerable to global price fluctuations, underscoring the need for diversification.

1.2.3. Social development and challenges

Ghana has made progress in human development over the decade but still grapples with poverty and inequality issues. Key social indicators and challenges include:

- **Poverty:** The country achieved reductions in poverty earlier in the 2000s, but progress stalled recently. As of 2023, an estimated 29.5% of Ghanaians lived in extreme poverty (on less than $2.15 per day).[19,20] This marks an increase of over 3 percentage points compared to a few years prior, largely due to the economic disruptions of COVID-19 and high inflation. Poverty is more concentrated in northern regions and rural areas. Rising living costs in 2022–2023 pushed more households into hardship, eroding gains made in the previous decade.
- **Inequality:** Income inequality remains high. Ghana's Gini coefficient was 43.5 in 2017 (the most recent available), indicating a sizable gap between rich and poor.[21] Wealth and opportunities are unevenly distributed, with poverty deepest in rural communities while urban middle classes have grown. Spatial inequality (between north and south, and between urban and rural) has also persisted or widened.[22] Such disparities pose social stability concerns and motivate government programs aimed at inclusive growth.

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[14] Adam M.A. (2024). The 2023 Annual Public Debt Report (Amended version). Ministry of Finance. Ghana.
[15] Focus Economics. Ghana Unemployment (% of active population, aop). https://www.focus-economics.com/country-indicator/ghana/unemployment. Accessed: 6/12/2024.
[16] World Bank (2021). Ghana Rising – Accelerating Economic Transformation and Creating Jobs. Washington, DC: The World Bank.
[17] Observatory of Economic Complexity (2023). Cocoa Beans (HS: 1801) Product Trade, Exporters. https://oec.world/en/profile/hs/cocoa-beans. Accessed: 6/12/2024.
[18] Akorlie C. (2023). Ghana returns to gold top spot as output jumps 32%. Thomson Reuters Foundation. https://www.reuters.com/markets/commodities/ghana-returns-gold-top-spot-output-jumps-32-2023-06-09. Accessed: 6/12/2024.
[19] IMF (2024). Ghana: Third review under the arrangement under the extended credit facility, request for modification of performance criteria, and financing assurances. International Monetary Fund. Washington, DC, United States.
[20] World Bank (2024). Sub-Saharan Africa: Macro Poverty Outlook. Country-by-country Analysis and Projections for the Developing World. Washington, DC: The World Bank.
[21] Wikipedia. List of countries by income inequality. https://en.wikipedia.org/wiki/List_of_countries_by_income_inequality. Accessed: 6/12/2024.
[22] World Bank (2023). Poverty & Equity Brief: Ghana. https://databankfiles.worldbank.org/public/ddpext_download/poverty/987B9C90-CB9F-4D93-AE8C-750588BF00QA/current/Global_POVEQ_GHA.pdf. Accessed: 6/12/2024.

- **Education:** Access to education has improved, though quality varies. Ghana achieved near-universal primary school enrollment and has significantly expanded secondary education in the last decade. A landmark Free Senior High School policy launched in 2017 eliminated tuition for public secondary schools, leading to record-high enrollments (over 470,000 students in Senior High School in 2017/18, the highest ever).[6] This has increased opportunities for youth, though it also strained resources (classroom space, materials). Literacy rates and primary completion have improved steadily. The current focus is on improving education quality and job-relevant skills, as well as sustaining financing for the larger student population.
- **Healthcare:** Ghana has made gradual progress in health outcomes, but challenges in access and quality persist. Life expectancy is 64 years,[23] up from roughly 60 years a decade ago. This reflects improvements in child survival, disease control, and general living conditions. The National Health Insurance Scheme provides basic coverage to many Ghanaians, and key health indicators like infant and maternal mortality have improved over time. Yet, healthcare access remains uneven, especially in rural areas where facilities and personnel are limited. Issues such as inadequate funding, infrastructure gaps, and regional disparities in health services continue to affect the population's well-being.

1.2.4. Climate-related vulnerabilities and adaptation

Ghana is increasingly vulnerable to the impacts of climate change, which have manifested in the past decade through higher temperatures and more unstable weather. Key climate-related challenges and responses include:

- **Rising Heat:** Average temperatures in Ghana have been climbing, and the country is experiencing a noticeable shift toward hotter conditions.[24] In recent years, heatwaves and unusually hot seasons have become more common.[24] For example, in early 2024 parts of Ghana saw temperatures exceed 40°C, prompting the national meteorological service to issue extreme heat warnings.[25] This growing heat stress threatens public health and reduces labour productivity, especially for outdoor work and agriculture.
- **Extreme Weather (Floods and Droughts):** Climate extremes such as floods and droughts have grown more frequent and severe, posing risks to agriculture, infrastructure, and livelihoods.[26] The northern savannah regions have suffered periodic droughts that damage crops and food security, while the south, including urban areas like Accra, faces intense rainfall and flash flooding. Notably, heavy floods have caused displacement and economic losses in several years of the past decade. These events underline Ghana's vulnerability to climate variability, which can set back development gains.
- **Coastal Erosion and Sea-Level Rise:** Ghana's coastal communities are under threat from the rising sea and coastal erosion. Sea levels along the Gulf of Guinea have been rising by about 2–3 mm per year, and projections suggest an increase on the order of 16 cm by 2050.[27] Erosion and tidal flooding already affect towns and infrastructure along the coast. Saltwater intrusion also endangers coastal farmland and wetlands. Without adaptation, coastal hazards could displace populations and damage assets in low-lying areas.

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[23] Statista.com (2025). Ghana: Life expectancy at birth from 2012 to 2022. https://www.statista.com/statistics/447515/life-expectancy-at-birth-in-ghana. Accessed: 6/2/2025.
[24] World Bank (2021). Climate risk country profile: Ghana. Washington, DC: World Bank.
[25] Prevention Web (2024). Climate change made West Africa's 'dangerous humid heatwave' 10 times more likely. https://www.preventionweb.net/news/climate-change-made-west-africas-dangerous-humid-heatwave-10-times-more-likely. Accessed: 6/12/2024.
[26] Desjonqueres C., Zhao H., Kosmidou-Bradley W., Corral P. (2024). Ghana's climate vulnerability profile. Washington, DC: World Bank.
[27] Ghana National Climate Change Adaptation Strategy (2012). CC DARE: Climate Change and Development — Adapting by REducing Vulnerability. A Joint UNEP/UNDP Programme for Sub-Saharan Africa funded by the Danish Ministry of Foreign Affairs. https://www.adaptation-undp.org/sites/default/files/resources/ghana_national_climate_change_adaptation_strategy_nccas.pdf. Accessed: 6/12/2024.

- **Adaptation Efforts:** The government has recognized climate risks and begun implementing adaptation strategies. Ghana formulated a National Climate Change Adaptation Strategy to increase resilience across sectors.[27] In practice, this has involved initiatives such as climate-smart agriculture (e.g., promoting drought-tolerant crops and improved irrigation) and disaster preparedness systems. Significant investments have gone into protecting coastal zones. For instance, 670 million USD was spent on sea defense projects in vulnerable shoreline areas over the last decade.[28] Ghana has also engaged in reforestation and tree-planting campaigns to restore ecosystems. Despite these efforts, the scale of needed adaptation is large. According to the Intergovernmental Panel on Climate Change (IPCC), West Africa is already experiencing widespread losses and damages from climate change, with warming trends unprecedented in 2,000 years.[29] Ghana's challenge ahead is to secure resources and implement plans to protect its people and economy against these intensifying climate pressures, while pursuing sustainable development pathways.[30]

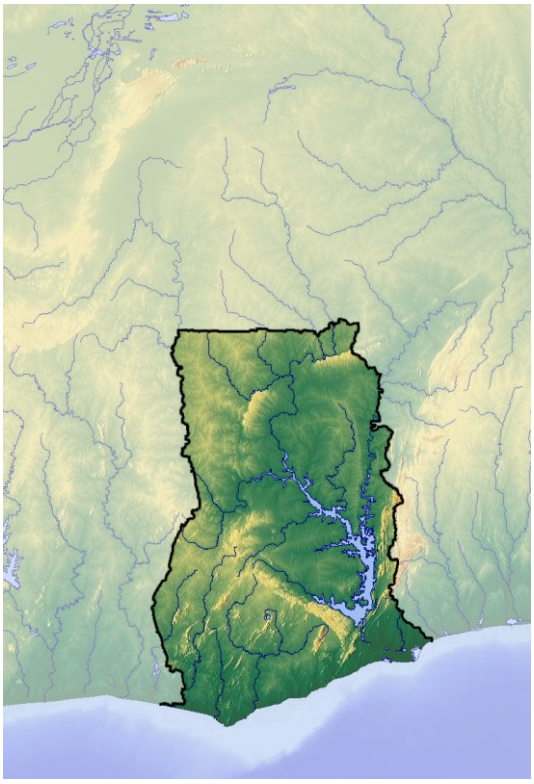
[28] Arhin, A. (2022). Climate Change Adaptation in Ghana: Strategies, Initiatives, and Practices. Working Paper No. 1. APRI: Berlin, Germany.
[29] Trisos C., Totin E., Adelekan I., Lennard C., Simpson N., New M. (2022). The IPCC'S Sixth Assessment Report. Impacts, adaptation options and investment areas for a climate-resilient West Africa. IPCC Regional Factsheet for decision-makers and climate change communicators in southern Africa.
[30] World Bank (2022). Country Climate and Development Report for Ghana. Washington, DC: World Bank.

2. Current and future heat exposure and climate change

2.1. Current weather and climate overview

Ghana is located in West Africa, adjacent to the Gulf of Guinea and the Atlantic Ocean to the south, sharing a border with Ivory Coast in the west, Burkina Faso in the north, and Togo in the east (Figure 1). Ghana has a tropical climate strongly influenced by the West African monsoon. Climate conditions vary by region. The south-eastern coastal belt is warm and relatively dry, the south-west is hot and humid, and the northern interior is hot and more arid.[24,30,32] Temperatures are generally high year-round, averaging around 27°C nationally, with the hottest conditions in the north (especially during the dry season).[24] Rainfall is unevenly distributed: annual precipitation ranges from about 1,100 mm in northern Ghana up to 2,100 mm in the rainier south-west,[24] while the far south-eastern coast receives as little as ~800 mm per year.[32] This gradient underpins distinct ecological zones, from savannah in the north to forest in the south.

Figure 1. Ghana physical map.[31]



Ghana's climate includes pronounced wet and dry seasons. The rainy season in the north is single-peaked, lasting roughly May to September.[24] In southern Ghana, rainfall is bimodal with two rainy seasons: a major season from April to July and a minor season from September to November.[24] Between December and March, a dry season prevails across the country, bringing hot, dry harmattan winds from the Sahara.[24] The harmattan period is characterized by very low humidity, hazy skies, hot days, and cooler nights before the rains return.[24]

Overall, the climate remains tropical with distinct wet/dry seasons, but higher temperatures, shifting rainfall patterns, and more extreme events in recent years indicate significant climate change impacts at the national level. The following trends highlight Ghana's growing climate variability:

- **Rising Temperatures:** Ghana has experienced a notable warming trend in recent decades. Mean annual temperatures have increased by about 1 °C since 1960, an average rise of ~0.2 °C per decade, with faster warming observed in the northern regions.[24] This is consistent with broader West African warming due to climate change.[24]
- **Changing Rainfall Patterns:** Rainfall patterns have become highly variable and unpredictable in recent years. Long-term records suggest a slight decline in total annual rainfall (around 2.4% per decade decrease from 1960 to 2006), even as year-to-year variability remains large.[24] Farmers and communities are reporting more erratic rainfall timing and distribution, which can disrupt planting seasons and water availability.[24]
- **Extreme Weather Events:** The frequency and intensity of extreme weather events are increasing. Ghana is experiencing more frequent and severe floods, droughts, and heatwaves in the past few decades.[24] These climate extremes pose growing risks to agriculture, infrastructure, and public health, and their impacts are not uniform across the country. Certain regions, such as the north for droughts or flood-prone areas in the south, are more severely affected.[24]

[31] The map was made using http://www.maps-for-free.com
[32] FAO (2005). Fertilizer use by crop in Ghana. Rome, Italy.

2.2. Choice of environmental indicators

To characterize the prevailing environmental conditions for work in Ghana, the present study used two key indicators: the monthly average maximum temperature and the monthly average maximum Wet-Bulb Globe Temperature (WBGT). The rationale for selecting these indicators and the specific time constant is provided below:

Air temperature: Temperature is the standard metric used by weather and climate experts when referring to general atmospheric conditions. However, the working environment is more complex, as it often involves additional factors such as high humidity, low wind, and exposure to thermal radiation from the sun or machinery. Consequently, air temperature alone does not fully capture the thermal stress experienced by workers.[33]

Wet-Bulb Globe Temperature (WBGT): The WBGT is the most widely adopted indicator by scientists and occupational health and safety professionals to assess heat stress in the workplace and its effects on health and productivity.[33,34,35,36] Unlike air temperature, the WBGT integrates several factors – air temperature, humidity, wind speed, and thermal radiation – to provide a more comprehensive measure of the heat load on the human body. Importantly, WBGT-based guidance takes into account work intensity and the use of personal protective equipment, making it especially useful for evaluating the risk of heat-related illnesses in occupational settings.

A recent series of large-scale multi-country evaluations of all the available indicators found that the WBGT is the most effective for evaluating the risk of heat-related illnesses for people who work in the heat.[33,37,38,39] A recent ILO analysis of legislation from countries across the world found that the WBGT is the most widely-used indicator of heat stress in the workplace.[1] Due to its strengths, the WBGT has been recommended by a number of national and international organizations for assessing heat stress including the ILO, the World Health Organization, and the World Meteorological Organization.[1,40] Detailed information regarding the methods used to estimate WBGT can be found in Annex 1.

Health and physical impacts of rising WBGT: As WBGT values increase, the human body experiences greater difficulty in dissipating heat, which can lead to a range of adverse effects. Elevated WBGT levels can cause:

- **Reduced physical performance:** Increased heat stress slows down movement and reduces overall work capacity, as the body prioritizes cooling over physical exertion.[41]

[33] Ioannou L.G., Tsoutsoubi L., Mantzios K., et al. (2022). Indicators to assess physiological heat strain - Part 3: Multi-country field evaluation and consensus recommendations. Temperature; 9(3): 274-291.
[34] NIOSH, Criteria for a recommended standard: occupational exposure to heat and hot environments, B. Jacklitsch, et al., Editors. 2016, Centers for Disease Control and Prevention. National Institute for Occupational Safety and Health. U.S. Department of Health and Human Services: Cincinnati, OH, USA.
[35] ISO, ISO 7243:2017 — Ergonomics of the thermal environment - Assessment of heat stress using the WBGT (wet bulb globe temperature) index. 2017, International Organization for Standardization: Geneva, Switzerland.
[36] ACGIH, Heat stress, TLVs and BEIs: threshold limit values for chemical substances and physical agents & biological exposure indices, ACGIH, Editor. 2020, ACGIH: Cincinnati.
[37] Ioannou L.G., Mantzios K., Tsoutsoubi L., et al. (2022). Indicators to assess physiological heat strain - Part 1: Systematic review. Temperature; 9(3): 227-262.
[38] Ioannou L.G., Dinas P.C., Notley S.R., et al. (2022). Indicators to assess physiological heat strain - Part 2: Delphi exercise. Temperature; 9(3): 263-273.
[39] Flouris A.D., Ioannou L.G., Nybo L. (2022). Working in a warming world: Translating thermal physiology to policy-relevant information. Temperature; 9(3): 223-226.
[40] World Health Organization and World Meteorological Organization (2025). Climate change and workplace heat stress: technical report and guidance. Geneva, Switzerland.
[41] Ioannou L.G., Foster J., Morris N.B., et al. (2022). Occupational heat strain in outdoor workers: A comprehensive review and meta-analysis. Temperature; 9(1): 67-102.

- **Cardiovascular strain:** The heart works harder to pump blood to the skin for cooling, which can lead to increased heart rate and long-term cardiovascular stress.[42]
- **Fatigue and cognitive impairment:** Higher WBGT levels are associated with quicker onset of fatigue and reduced cognitive function, impacting decision-making and coordination.[1,43,44]
- **Heat-related illnesses:** Prolonged exposure can result in dehydration, heat cramps, heat exhaustion, or even heat stroke, especially in high-intensity work environments.[1,42] Working in a hot environment for a significant part of the year can lead to acute/chronic kidney injury.[1,42]

Choice of time constant: The analysis employs the monthly average maximum values for both temperature and WBGT because these values are typically observed between 12:00 and 14:00 – the period when most workers are active. This approach ensures that the indicators accurately represent the most challenging conditions encountered during the workday.

2.3. Current heat and environmental conditions

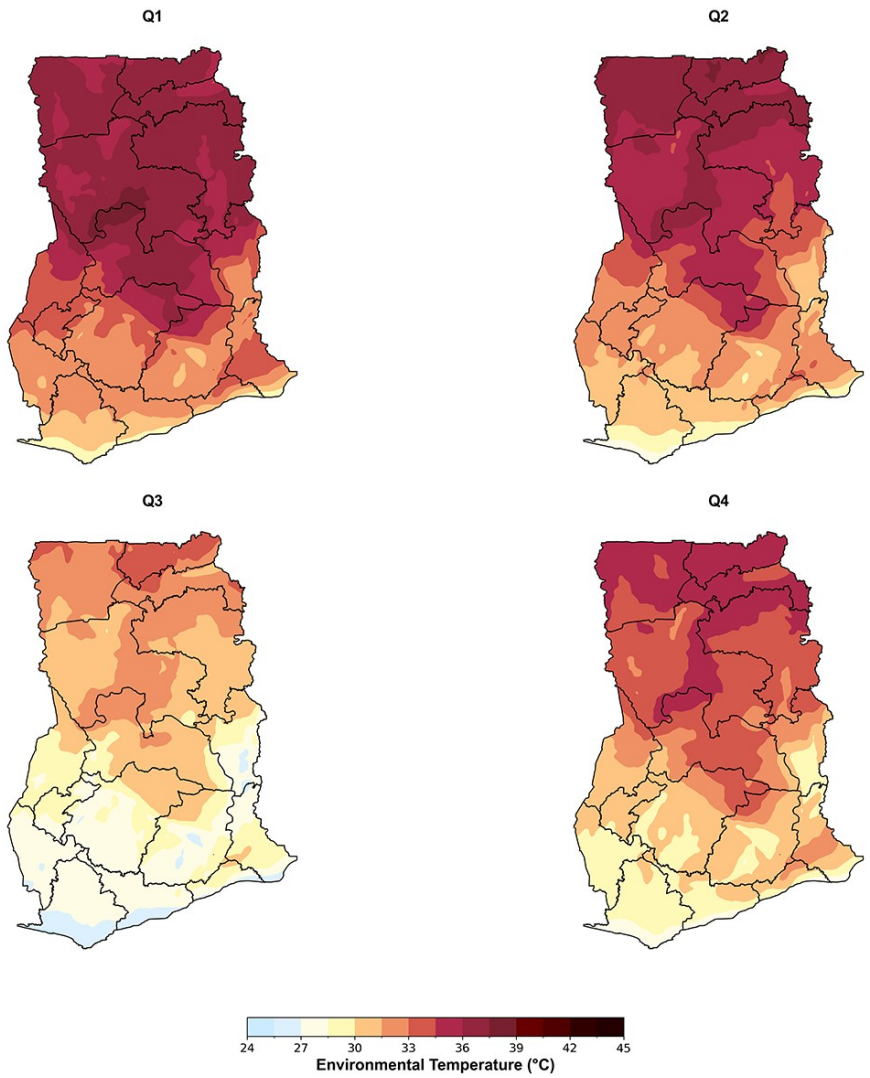
Figure 2 illustrates the quarterly average maximum environmental temperatures across Ghana. The maps reveal a persistent north–south thermal gradient throughout the year. The Sahelian and Guinea savannah zones in the north record the highest quarterly maxima in all seasons, while the forest and coastal belts in the south remain comparatively cooler, reflecting maritime influence, higher cloud cover, and vegetation effects. Localised variation is evident over the middle belt and along parts of the coast, but the broad gradient dominates.

Seasonal cycle

- **Q1 (Jan-Mar)** is the hottest period, with widespread very high maxima over the northern half and the transition zone. This aligns with the late dry-season/pre-monsoon heat build-up, with clear skies and strong insolation.
- **Q2 (Apr-Jun)** remains very hot in the north and interior, while the south begins to moderate as rains and cloudiness advance from the Gulf of Guinea inland.
- **Q3 (Jul-Sep)** shows the coolest maxima nationwide, coinciding with the peak monsoon. Cooling is strongest across the southern and south-western regions, where persistent rainfall and cloud reduce daytime heating.
- **Q4 (Oct-Dec)** is a transition back to warmer conditions, with heat re-intensifying over the northern regions as rainfall retreats, while the south stays relatively moderate.

[42] Flouris A.D., Dinas P.C., Ioannou L.G., Nybo L., Havenith G., Kenny G.P., Kjellstrom T. (2018). Workers' health and productivity under occupational heat strain: a systematic review and meta-analysis. Lancet Planetary Health; 2(12): e521-e531.
[43] Flouris A.D. (2019). Human thermoregulation. in: Périard J., Racinais S., eds. Heat stress in sport and exercise: Springer.
[44] Flouris AD, Schlader ZJ. (2015). Human behavioral thermoregulation during exercise in the heat. Scandinavian Journal of Medicine and Science in Sports; 25 (S1): 52-64.

Figure 2. Quarterly average maximum environmental temperature across Ghana during the reference historical period (1985-2014).



Implications for labour and OSH planning

- The highest occupational heat-risk windows from air-temperature maxima occur in Q1-Q2, particularly across Northern, Upper East/West, Savannah, Northeast, and Oti regions, and parts of the middle belt.
- Q3 provides relative relief, especially in the south, before a partial rebound in Q4, primarily in the north.
- Given this geography and seasonality, seasonal scheduling (earlier starts/longer mid-day breaks) and targeted heat-risk management should prioritise northern and interior regions in Q1-Q2, with continued monitoring in Q4. Urban heat-island effects in major cities (e.g., Accra, Kumasi, Tamale) may create local hotspots that exceed surrounding areas and warrant site-specific controls.

Figure 3 illustrates the quarterly average maximum WBGT across Ghana. WBGT is an important measure of heat stress, taking into account not only temperature but also humidity, wind speed, and solar radiation, which makes it particularly useful in assessing the risk of heat stress for working people. The maps show a persistent north-south gradient in heat stress throughout the year. The Northern, Upper East/West, Savannah and Northeast regions consistently register the highest quarterly average maximum WBGT, while the forest and coastal belts in the south remain comparatively lower.

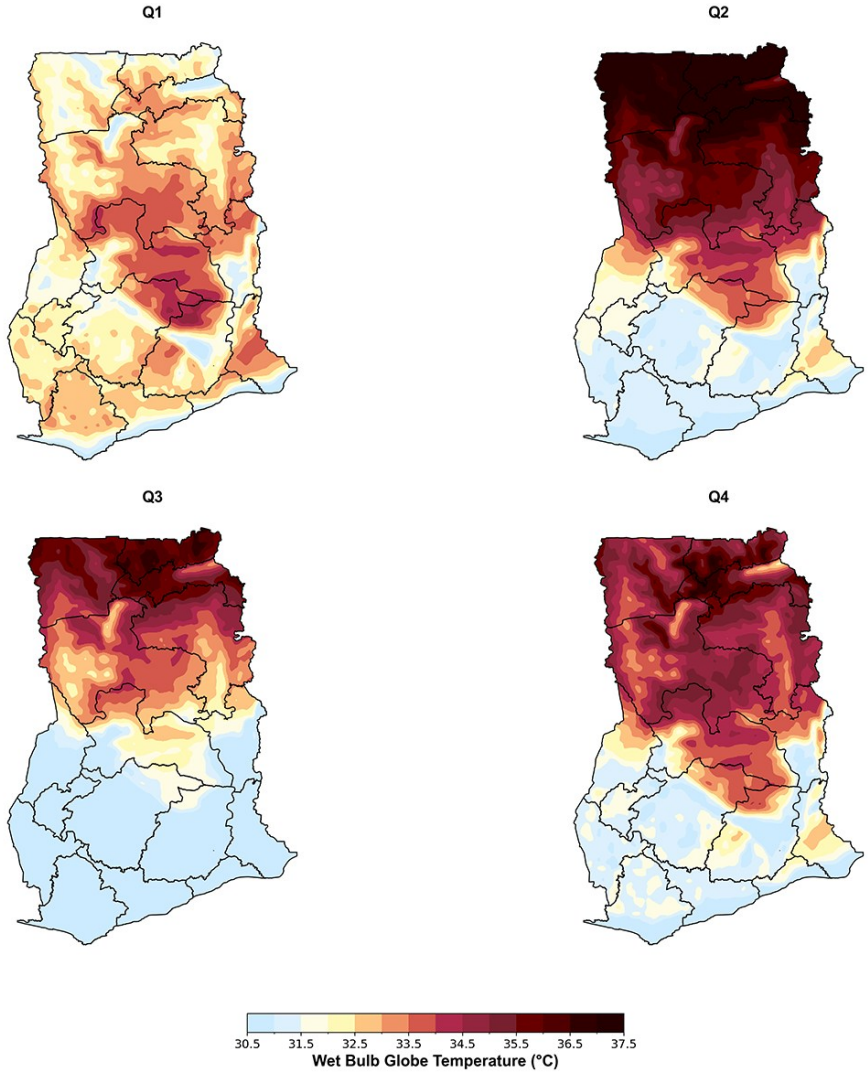
Seasonality

- **Q1 (Jan-Mar)** shows generally moderate to high WBGT across the interior, with localized hot pockets in the middle belt, but the southern coast remains relatively lower.
- **Q2 (Apr-Jun)** marks a sharp escalation, with a broad swath of the north reaching extreme WBGT levels (35-37.5°C), indicating conditions under which continuous moderate-to-heavy work is unsafe without strong controls (water-rest-shade, task rotation, cooling/ventilation).
- **Q3 (Jul-Sep)** maintains very high WBGT in the north, while the south experiences its lowest values of the year, reflecting the peak rainy season with greater cloud cover and ventilation.
- **Q4 (Oct-Dec)** retains WBGT elevated across the north and much of the middle belt of the country, with only the southern regions returning to lower heat levels.

Implications for labour and OSH planning

The primary occupational heat-risk window spans Q2-Q4 in northern and interior regions, where many outdoor and high-exertion activities (construction, agriculture, small-scale mining, transport) will require WBGT-based work-rest scheduling, access to shade and hydration, and health monitoring protocols – particularly in Q2. The south shows a pronounced seasonal relief particularly in Q3, but humid-heat episodes still occur and should be managed using WBGT thresholds rather than air temperature alone. Urban centres (e.g., Tamale, Kumasi, Accra) may experience localised hotspots due to urban heat-island and low-wind conditions, underscoring the need for site-specific monitoring and controls even within regions mapped as relatively cooler.

Figure 3. Quarterly average maximum WBGT across Ghana during the reference historical period (1985-2014).



2.3.1. Findings from comparing temperature against WBGT

Across quarters, WBGT indicates higher and more persistent risk than temperature alone, particularly in the northern half of Ghana, where humid-heat and light winds keep stress elevated even when air temperature eases. When comparing the maps showing environmental temperature against those illustrating the WBGT, the following key insights emerge:

Seasonal trends

- **Q1 (Jan-Mar):** Air temperature is very high in the north and interior, while it remains relatively milder in the south and coast. WBGT is moderate-to-high over much of the country with hotspots in the middle belt not yet reaching the year's extremes. This reflects relatively drier conditions despite high air temperatures.
- **Q2 (Apr-Jun):** Air temperature remains very high, especially in the north/interior. The WBGT shows a sharp escalation with a broad swath of the north and transition zone reaching extreme WBGT

(approaching the limits of survivability), indicating conditions where continuous moderate-to-heavy work is unsafe without strong controls.

- **Q3 (Jul-Sep):** Temperature readings indicate this as the coolest quarter nationwide, particularly in the south under peak monsoon. The WBGT shows that the north stays at very high WBGT, while the south drops to the lowest levels. This means that, despite cooler air, northern humid-heat and reduced wind keep physiological stress high.
- **Q4 (Oct-Dec):** Temperature indicates that warming returns, most pronounced in the north. The WBGT remains widely elevated in the north and much of the middle belt, producing a second long high-risk window as rains retreat but humidity persists in much of the country.

Spatial contrasts and divergences

- **Persistent north–south gradient:** Both indicators show the north hotter/riskier than the forest/coastal south, but WBGT expands the risk belt farther south than temperature alone suggests.
- **Middle belt amplification:** In Q1-Q2, WBGT highlights hot corridors across the transition/middle belt that are less prominent on the temperature maps. This is evidence of humidity/solar effects.
- **Southern relief in Q3:** Temperature and WBGT both show relief in the south, but WBGT shows a much stronger drop, underscoring the protective role of cloud, rain and wind during peak monsoon.

Implications for labour risk management

- **Primary high-risk period:** Q2-Q4 for the north and transition zone (Northern, Upper East/West, Savannah, Northeast, Oti). Q3 is not a relief there despite cooler air, indicating that controls must remain in place.
- **Southern strategy:** Q3 offers the best scheduling window for heat-exposed work in the southern forest/coastal regions; Other quarters still require precautions during hot spells.
- **Decision metric:** Use WBGT-based thresholds to trigger work-rest cycles, shaded/ventilated rest areas, hydration plans, and task rotation, rather than air temperature alone.
- **Urban hotspots:** Major cities (e.g., Tamale, Kumasi, Accra) may exceed surrounding areas due to urban heat-island and low-wind conditions. Site-level WBGT monitoring is warranted in these locations.

Overall, temperature maps capture the broad seasonal heat pattern (peak Q1-Q2, minimum Q3), but WBGT maps identify when and where workers' heat strain actually peaks: Q2-Q4 across the north and transition belt; Q1 is the hottest part of the year in the south. Policy and workplace protections should, therefore, be timed and targeted using WBGT, not temperature alone.

2.4. Climate projections

2.4.1. Country overview

Ghana has a tropical climate with a marked wet-dry seasonal cycle, featuring single or double rainy seasons depending on the region. Historically, mean temperatures around 27°C are rising, with about 1°C of warming since the 1960s. Rainfall patterns are becoming more variable, including more frequent heavy rainfall events and lengthier dry spells. These changes pose greater risks of droughts, floods, and coastal erosion, threatening development gains if not addressed. Below are the main impacts on key industries:

- **Agriculture:** Ghana's agriculture (including crops, livestock, forestry, and fisheries) employs over half the workforce and contributes ~20% of GDP.[24] It is predominantly rain-fed, so shifting rainfall and rising heat can depress yields.[24] For instance, cocoa could lose significant growing areas under higher temperatures.[24] Flooding episodes, such as the 2007 northern floods, have caused sizable crop losses and displacement.[24]

- **Mining and Extractive Industries:** Ghana is endowed with significant mineral and fossil resources – notably gold, bauxite, and more recently oil and gas – which form a critical part of its industrial sector.[24] Mining (especially gold extraction) and petroleum contribute substantially to export revenues and GDP.[24] However, water scarcity (during droughts) or infrastructure damage (during floods) disrupts operations. Heavier rainfall can flood mines or tailings dams, while hydropower constraints reduce energy supply for refineries and processing.[24]
- **Manufacturing:** Manufacturing in Ghana spans agro-processing, textiles, chemicals, cement, and small-scale industries. This sector often relies on steady inputs from agriculture and mining, and on stable infrastructure services (power, water, transport).[24] As such, climate impacts on other sectors tend to cascade into manufacturing. Unpredictable weather and energy shortfalls from low hydro reservoir levels frequently impede output.[24] Urban flooding can damage roads or factories, further hitting manufacturing productivity.[24]
- **Services:** Ghana's service sector forms the largest share of GDP. Floods repeatedly disrupt Accra and other urban centers, blocking transport and commerce.[24] Beach erosion and unpredictable rainfall also strain tourism, a growing service area.[24]

These climate challenges emphasize the need for robust adaptation strategies to protect both the environment and the livelihoods of communities dependent on agriculture and tourism.

Detailed climate change trends against natural variability are illustrated in Figure 4. These trends illustrate a consistent upward trend in temperatures, with steeper slopes observed in the recent decades, indicating an acceleration in warming (Figure 4, top left graph), as well as that warming has become more pronounced in Ghana during the recent decades (particularly in the period 2010-2014) (Figure 4, top right graph). In addition, the available evidence reveals a clear shift in the distribution of average mean surface air temperatures in Ghana in the 30-year period until 2014 (Figure 4, bottom left graph). Finally, the evidence gathered thus far shows an increasing frequency and intensity of extreme temperature events (Figure 4, bottom right graph).

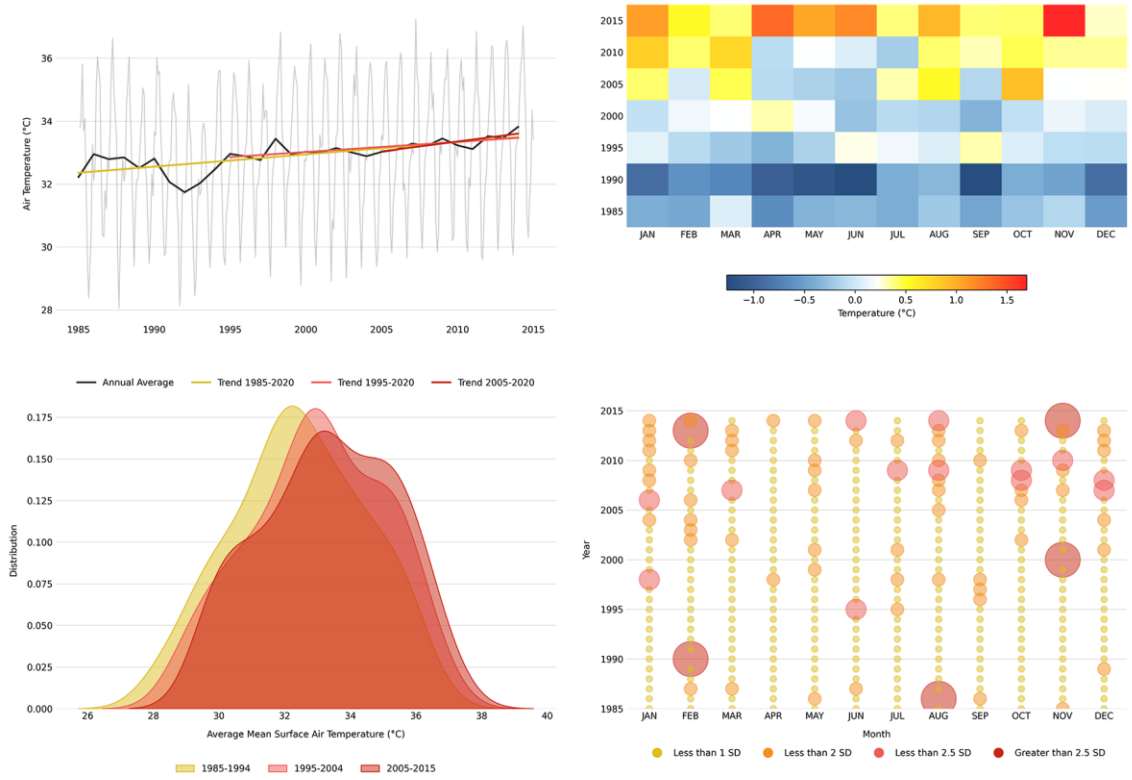
Collectively, the available evidence demonstrates a clear and accelerating warming trend in Ghana in the 30-year period until 2014:

- Average maximum temperatures have increased significantly, as indicated by the shift in distributions and steeper annual trends over recent decades.
- The occurrence and intensity of extreme temperature events, particularly in the warmer months, have grown substantially since 2010.
- Monthly temperature trends reveal that warming is not limited to specific seasons but it occurs almost the entire year.
- The trends highlight the growing impact of climate change in Ghana, posing significant challenges to the environment, economy, and public health.

Taken together, these findings emphasize the urgent need for adaptive measures to address rising temperatures and extreme heat events, particularly given Ghana's vulnerability to climate change and its dependence on sectors such as agriculture and services, which are highly sensitive to climatic variations.

The economic impact of climate change will not be uniform across Ghana, with rural communities in the north likely facing disproportionate challenges. Sectors such as agriculture and services, which are central to Ghana's economy, are particularly exposed to climate risks. The projected increase in extreme weather events, such as heatwaves, intense rains, and droughts, threatens to disrupt these sectors, potentially impacting employment and income for a significant portion of the population.

Figure 4. Climatological averages and trends of change against natural climate variability in Ghana during the period 1985-2015: average mean surface air temperature with linear trend lines per decade (top left); average mean surface air temperature monthly trends (top right); change in distribution of average mean surface air temperature (bottom left); change in intensity of extreme daily maximum temperature events (bottom right).



2.4.2. Climate change scenarios

To understand how future heat conditions might affect work in Ghana, the present study uses four "storylines" known as Shared Socioeconomic Pathways (SSPs). These scenarios were used by the IPCC Sixth Assessment Report[45] to describe different ways our society might evolve based on our choices about energy use, technology, and environmental policies. The scenario characteristics are summarized in Table 1.

Following standard practice,[45] the present analysis uses specific codes that combine the SSP number with an expected level of greenhouse gas influence – measured as radiative forcing in watts per square meter (W/m^2) – by the year 2100. The radiative forcing level indicates the strength of the warming effect observed at the end of the century, resulting in the following codes: SSP1-2.6, SSP2-4.5, SSP3-7.0, and SSP5-8.5.

[45] IPCC (2021). Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. V. Masson-Delmotte, P. Zhai, A. Pirani et al. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, Intergovernmental Panel on Climate Change.

Table 1. Characteristics of the global SSPs used in the present study.

SSP	Scenario	Estimated warming (2041-2060)	Estimated warming (2081-2100)	Very likely range in °C (2081-2100)
SSP1-2.6 (Sustainability Pathway)	**Low GHG emissions** CO_2 emissions cut to net zero around 2075	1.7	1.8	1.3 – 2.4
SSP2-4.5 (Middle of the Road Pathway)	**Intermediate GHG emissions** CO_2 emissions around current levels until 2050, then falling but not reaching net zero by 2100	2.0	2.7	2.1 – 3.5
SSP3-7.0 (Regional Rivalry Pathway)	**High GHG emissions** CO_2 emissions double by 2100	2.1	3.6	2.8 – 4.6
SSP5-8.5 (Fossil-fueled Development Pathway)	**Very high GHG emissions** CO_2 emissions triple by 2075	2.4	4.4	3.3 – 5.7

Note: Detailed information for the methods used to calculate the SSPs-related analyses can be found in Annex 1.

Key: GHG = greenhouse gas.

It is important to note that there are several other SSPs and radiative forcing combinations available.[45] However, the present study focuses only on these four scenarios because they represent a wide range of potential futures – from a highly sustainable pathway to one that relies heavily on fossil fuels – and provide clear contrasts in terms of expected climate impacts. This selection helps illustrate the range of possible outcomes in a straightforward manner while keeping the analysis accessible and focused.

What are the SSPs?

The SSPs are narratives used by climate scientists to explore how different levels of greenhouse gas emissions might impact our world. In simple terms, they help us imagine a range of possible futures: from a sustainable world with clean energy to one that continues heavy use of fossil fuels.

The four scenarios of the future considered in the present study are as follows:

- **SSP1 – Sustainability (Taking the Green Road):** In this scenario, countries work together to adopt clean energy and sustainable practices. As a result, global warming is limited, with temperature increases by the year 2100 of about 1.3°C to 2.4°C above pre-industrial levels. The "2.6" added next to the SSP1 code indicates that the warming influence (radiative forcing) is expected to reach roughly 2.6 W/m^2 by 2100.

  On the development front, the world in this scenario shifts gradually, but steadily, toward a more sustainable path, characterized by more inclusive development and a respect for environmental issues. Investments in education, health, and social protection accelerate the demographic transition, while policy reforms internalise environmental costs and improve stewardship of global commons. Economic objectives broaden from pure GDP growth to human-well-being; material consumption grows slowly and becomes markedly less resource- and energy-intensive. As a result, both inter- and intra-country inequality decline.

- **SSP2 – Middle of the Road:** This scenario follows current trends with moderate improvements in technology and environmental policies. This results in a moderate temperature rise of approximately 2.1°C to 3.5°C by the year 2100. The "4.5" added next to the SSP2 code means the radiative forcing is projected to be around 4.5 W/m^2 by 2100.

  The socio-economic and technological trends in this scenario largely continue along the historical patterns. Development and income growth proceeds unevenly, with some countries making relatively good progress while others perform below expectations. Moderate population growth levels off after mid-century and resource efficiency improves gradually, yet progress toward the Sustainable Development Goals (SDGs) is uneven. Environmental pressures ease in some areas but persist in others; vulnerability to shocks remains significant where institutions are weak. Income inequality persists or marginally improves, while the challenges for addressing vulnerability to societal and environmental changes persist.

- **SSP3 – Regional Rivalry (A Rocky Road):** In this pathway, countries tend to prioritize national interests over international cooperation, leading to slower progress on clean technologies and climate policies. This scenario could lead to higher warming of about 2.8°C to 4.6°C, due to a radiative forcing level near 7.0 W/m^2 by 2100, which is reflected in the SSP3 code used in the present study.

  In this scenario, geopolitical fragmentation, resurgent nationalism and concerns over security lead countries to prioritise domestic or, at most, regional self-sufficiency. Countries prioritize achieving energy and food security goals within their own regions at the expense of broader-based development. Trade barriers rise and investment in education, technology and cross-border cooperation declines. Economic development is slow, consumption is material-intensive, inequalities persist or worsen (particularly in emerging economies), and environmental degradation accelerates in several regions. Population growth stagnates in industrialized but rises fast in developing countries.

- **SSP5 – Fossil-Fueled Development (Taking the Highway):** This future envisions rapid economic growth powered largely by fossil fuels, with limited efforts to limit emissions. This pathway may lead to the highest warming, with temperature increases exceeding 5°C by the year 2100. The "8.5" added next to the SSP5 code reflects an expected radiative forcing of approximately 8.5 W/m^2 by 2100.

  Integrated global markets and robust institutions foster technological breakthroughs in this scenario. There are also strong investments in health, education, and institutions to enhance human and social capital. The strong faith in markets and innovation drives rapid economic expansion and rising living standards. These factors lead to rapid global economic growth, while global population peaks and declines by the end of the century. However, growth is powered by abundant fossil fuels and energy-intensive life-styles. Local environmental issues such as air pollution are successfully managed, and confidence grows in large-scale technological fixes, including potential geo-engineering.

The IPCC Sixth report does not estimate the likelihood of the four tested scenarios. The rise in heat levels will depend on which mitigation pathway and policies countries collectively and independently pursue.[45]

The tested SSPs are not predictions but rather tools that help explore a range of possible futures. By comparing these outcomes, the present study illustrates how different policy and economic choices today could influence the working conditions and heat stress risks in Ghana tomorrow.

Implications of SSPs for labour markets and policy interventions

From an ILO standpoint, the SSPs highlight differing socioeconomic and governance contexts that affect labour markets. For instance, SSP1's focus on sustainability and equity could spur the creation of green jobs and improved working conditions, while SSP3's emphasis on regional rivalries and weak collaboration might hamper labour standards and stifle investment in social protection. SSP5 suggests robust economic growth but continued dependency on fossil fuels, which could raise long-term occupational risks in certain industries.

Combining the SSPs with different greenhouse gas concentration trajectories allows for comprehensive assessments of future risks and opportunities. The SSPs are used to test labour policies, design social protection measures, and plan for just transitions to low-carbon industries. By anticipating how diverse SSPs shape workforce needs and climate challenges, stakeholders can develop strategies that safeguard workers' well-being and promote sustainable and inclusive growth.

Connecting global SSPs to national strategies for Ghana

While the SSPs are developed as global scenarios, they provide critical insights for national decision-makers, including those in Ghana. These scenarios illustrate how different paths in energy use, economic growth, and policy decisions could shape the climate and, consequently, the environmental conditions that affect daily life and work. For Ghana, the varying outcomes depicted by the SSPs – ranging from sustainable pathways with limited warming (SSP1-2.6) to fossil-fueled development leading to severe warming (SSP5-8.5) – are directly linked to the country's future labour conditions, economic stability, and public health.

By considering these global SSPs, Ghanaian policymakers can better understand the potential risks and opportunities that different climate futures may bring. For instance, adopting

policies aligned with a more sustainable scenario (e.g., SSP1-2.6) could help mitigate the severity of heat stress, protect worker health, and reduce economic losses from reduced productivity. Conversely, inaction or insufficient adaptation measures (e.g., SSP5-8.5) may expose Ghana to extreme heat conditions, with significant repercussions for labour productivity and overall economic resilience. In essence, the global SSPs are not abstract projections. They serve as practical tools that inform national strategies, enabling Ghana to tailor its climate adaptation and economic policies to protect its citizens and secure a more stable, sustainable future.

2.4.3. Future heat conditions

The monthly maximum average environmental temperature and WBGT during the reference historical period (1985-2014) ranged between 32°C and 34°C (Figure 5). Across all SSPs, the analysis suggests a clear warming trend, with varying degrees of severity depending on the scenario. Even in the most optimistic scenarios (SSP1-2.6 and SSP2-4.5), Ghana will face increases of 1.2°C environmental temperature and WBGT. The scenarios with high emissions (SSP3-7.0 and SSP5-8.5) suggest more significant warming of up to 6°C environmental temperature and WBGT. Without effective adaptation strategies, these would lead to significant health impacts and severely reduce the capacity to perform manual labour.

Figure 5. Average maximum environmental temperature (top) and WBGT (bottom) with 95% confidence intervals in the reference historical period (1985-2014) and until 2100 across the different SSPs.

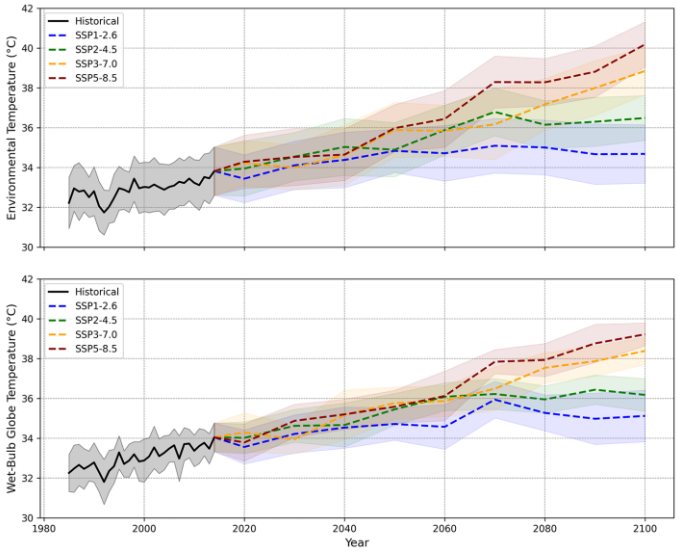
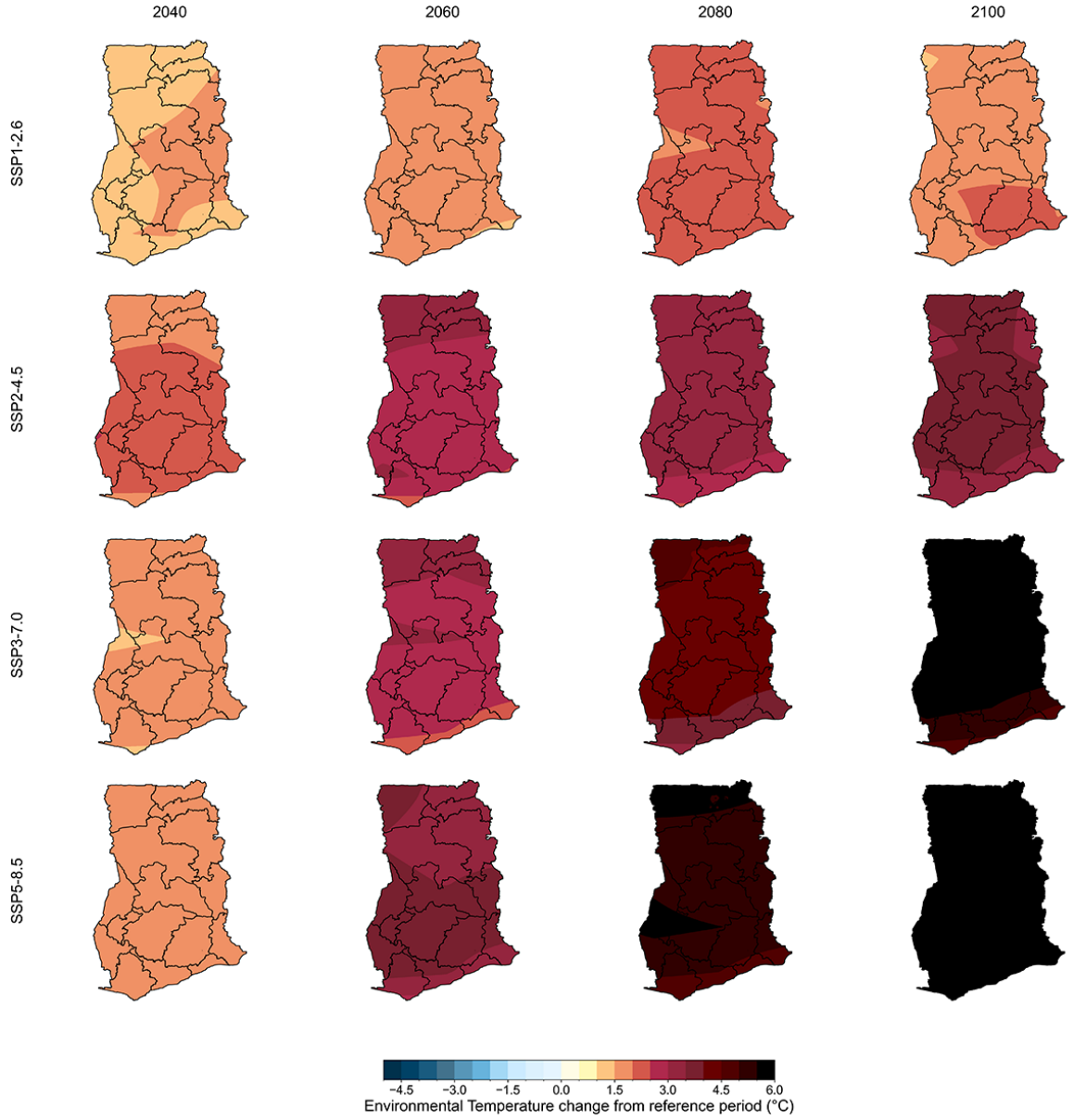


Figure 6 illustrates the change in environmental temperature compared to the reference historical period across the different SSPs and at different time points until the end of the century. The maps show a steady rise in average maximum temperature across Ghana under every pathway and at every time point. The trend strengthens with time and with higher global emissions.

Figure 6. Change in the average maximum environmental temperature in Ghana compared to the reference historical period (1985-2014) across the different SSPs and at different time points during this century.



By 2040 most of the country is about one to two degrees warmer than the 1985 to 2014 historical period. Differences between pathways are still small at that point. Under SSP1-2.6 the increase remains moderate and tends to level off after mid-century. By 2100, the level of warming reaches 2.0-2.5°C. Under SSP2-4.5, the warming continues and reaches roughly 3-4°C by century end. Under SSP3-7.0, warming accelerates after mid-century and approaches 5°C by 2100. Under SSP5-8.5, the country reaches 6°C or more by the end of the century.

The warming pattern is fairly uniform in space. The north and interior typically warm slightly more than the coast in the higher emissions pathways late in the century. All regions of the country will experience warming. Areas that are already hot move into new extremes, while cooler regions in the south will also warm.

These results carry clear policy recommendations. The near-term increase of 1-2°C is already locked in and calls for adaptation of work scheduling, heat safety, and urban planning. The choice of global pathway then determines the late century burden. A Paris aligned path would avoid about 3-4°C of extra warming by 2100 compared with a high fossil fuel consumption path. That gap translates into fewer days above critical heat thresholds at work and lower productivity losses.

The change in WBGT compared to the reference historical period across the different SSPs and at different time points until the end of the century is illustrated in Figure 7. The results follow closely those for environmental temperature, showing a steady rise in maximum WBGT across Ghana in every future. The warming grows with time and with higher global emissions. By 2040 most regions are already 1-2°C above the 1985 to 2014 historical baseline. Differences between emission pathways are still small at that point. In the low emissions case SSP1-2.6, the temperature rise remains moderate and tends to level off after mid-century. By 2100 most areas are about 2°C warmer. In the middle path SSP2-4.5, the increase continues to about 3-4°C by century end. In SSP3-7.0, the rise accelerates after mid-century and approaches 5-6°C by 2100. In SSP5-8.5, almost the whole country reaches increases near or above 6°C by late century.

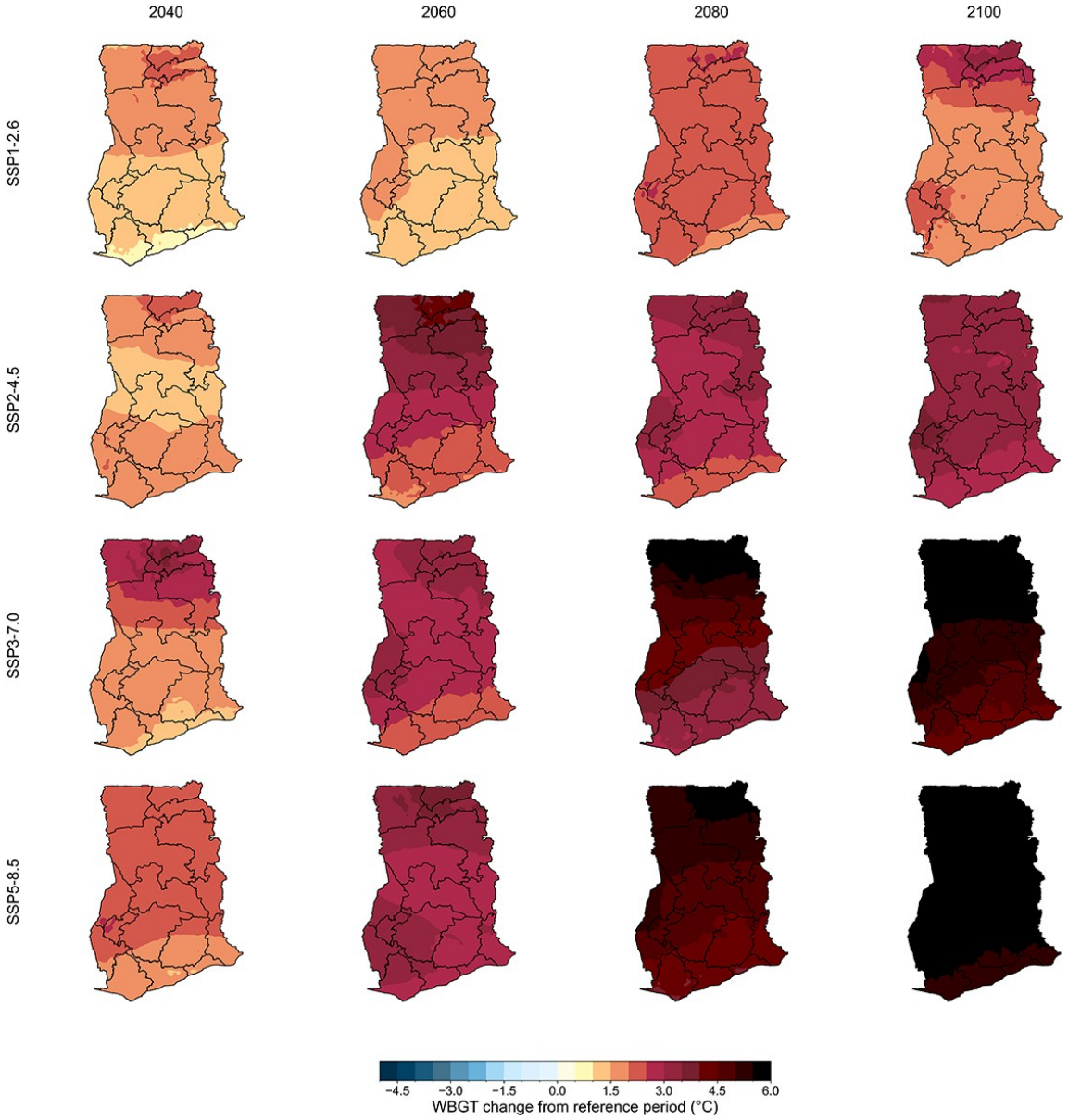
The pattern in space is broad and consistent, especially in the high emissions scenarios. Northern and interior regions show the largest early increases. Coastal and forest zones follow closely. By late century, the entire country converges to very high values in the higher emissions pathways. The estimated predictions will impact work. WBGT combines heat, humidity, wind, and sun. A rise of even one to two degrees Celsius moves many days across safety thresholds for moderate and heavy work. The higher emissions pathways imply many more hours when outdoor labour is unsafe without strong protections. The difference between the low and high emissions pathways is about 5°C. Avoiding these extra degrees of WBGT by 2100 would prevent a sharp escalation in lost work time and heat illness risk.

3. Loss of work capacity by sector of activity

3.1. Overview of economic activity sectors

Ghana's economy features agriculture as a pillar, primarily rain-fed and thus sensitive to weather variability, followed by construction, which has recently slowed but remains important for public infrastructure and urban housing. Manufacturing constitutes roughly 11% of GDP, focusing on agro-processing and growing steadily with government support. Mining and extractives are capital-intensive yet crucial to export revenues, especially for gold and oil. Services dominate overall output, spanning finance, information and communication technologies, and a recovering tourism sub-sector. Finally, transportation, logistics, and trade support economic activity through vital road networks and busy ports.

Figure 7. Change in the average maximum WBGT in Ghana compared to the reference historical period (1985-2014) across the different SSPs and at different time points during this century.



1. **Agriculture:** This sector, which includes crops, livestock, forestry, and fishing, accounts for about 21% of Ghana's GDP[46] and engages roughly 40% of its workforce.[47] Agriculture has shown moderate growth in recent years (around 4-5% annually). For example, agricultural output grew by 4.5% year-on-year in late 2023.[46] Key staples include cocoa, a major export crop.[46] However, Ghana's largely rain-fed agriculture is vulnerable to climate variability, with irregular rainfall already impacting farm productivity and rural incomes.[48]
2. **Construction:** The construction industry contributes approximately 8% of Ghana's GDP[49] and employs over half a million people (predominantly male workers).[50] After a period of expansion, the sector has recently slowed amid economic challenges. Notably, construction output contracted by about 12.8% year-on-year in the fourth quarter of 2023.[46] Despite this downturn, ongoing public infrastructure projects and urban housing demand continue to drive activity in this sector, which remains an important component of industrial growth and urban employment.
3. **Manufacturing:** The manufacturing sector makes up roughly 11% of Ghana's GDP[51] and provides over one million jobs in industries such as agro-processing, textiles, and chemicals.[50] The sector's growth has been modest but positive. For instance, manufacturing output grew about 4.1% year-on-year in 2023.[46] Food and beverage processing is a significant sub-sector, reflecting efforts to add value to agricultural products. The government has prioritized industrialization (e.g. "One District, One Factory" initiatives) to further boost manufacturing, aiming to reduce imports by producing more goods domestically and creating jobs in higher value-added activities.[52]
4. **Mining and extractives:** These industries (notably gold mining as well as oil and gas production) contribute around 10-12% of Ghana's GDP.[49] This sector is capital-intensive and employs only a small fraction of the workforce (about 1%).[50] Ghana is Africa's second-largest gold producer, and petroleum has become a significant industry since oil production began in the last decade.[24]
5. **Services:** This is the largest segment of Ghana's economy, contributing roughly 45% of GDP[46] and about 41% of total employment.[53] This broad sector includes finance, information and communication technology, tourism, trade, education, and other services. Financial services as well as telecommunication technologies have expanded rapidly. For instance, the information and communication technology sub-sector grew nearly 17.9% year-on-year in 2024,[46] reflecting a boom in digital services. Tourism is also rebounding post-pandemic. The travel and tourism sector contributed

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[46] Ghana Statistical Service (2024). Quarterly Gross Domestic Product (QGDP) - Fourth Quarter 2023. https://statsghana.gov.gh/gssmain/fileUpload/National%20Accounts/Newsletter_Quarterly_GDP_2023_Q4%20March_2024%20Edition.pdf. Accessed: 6/12/2024.

[47] FAO (2019). Promoting sustainable development for agricultural transformation, economic growth and rural development in Ghana. Food and Agriculture Organization of the United Nations. https://openknowledge.fao.org/server/api/core/bitstreams/f34b0635-83ad-4ca4-a38d-b3019c01da90/content. Accessed: 6/12/2024.

[48] US Department of Agriculture, Foreign Agricultural Service (2023). Ghana Climate Change Report. https://apps.fas.usda.gov/newgainapi/api/Report/DownloadReportByFileName?fileName=Ghana%20Climate%20Change%20Report%20_Accra_Ghana_GH2023-0008.pdf. Accessed: 6/12/2024.

[49] FX Empire (2024). Ghana GDP Annual Growth Rate. https://www.fxempire.com/macro/ghana/gdp-annual-growth-rate. Accessed: 6/12/2024.

[50] Ghana Statistical Service (2022). Quarterly Labour Force Report. Ghana Annual Household Income and Expenditure Survey. www.statsghana.gov.gh/gssmain/fileUpload/pressrelease/AHIES%202022%20Q1%20and%20Q2%20Labour%20Force%20Report.pdf. Accessed: 6/12/2024.

[51] Trading Economics (2025). Ghana - Manufacturing, Value Added (% Of GDP). https://tradingeconomics.com/ghana/manufacturing-value-added-percent-of-gdp-wb-data.html. Accessed: 2/2/2025.

[52] World Bank (2017). Ghana: Agriculture Sector Policy Note. Transforming Agriculture for Economic Growth, Job Creation and Food Security. Washington, DC: The World Bank.

[53] Statista.com (2024). Ghana: Distribution of employment by economic sector from 2012 to 2022. https://www.statista.com/statistics/447530/employment-by-economic-sector-in-ghana. Accessed: 6/12/2024.

about USD 3.4 billion to GDP in 2022 as international arrivals recovered.[54] Overall, services sector growth has been steady (around 4–5% in 2023),[55] making it a key driver of GDP and employment in Ghana.

6. **Transportation and trade:** These sectors form the backbone of commerce in Ghana. The transport and storage sub-sector alone contribute about 10% of GDP,[49] underlining Ghana's role as a transit hub with busy ports (Tema and Takoradi) and improving road networks. Trade is vital both domestically and internationally – exports of goods and services are equivalent to roughly 48% of GDP.[49] Wholesale and retail trade is one of the country's largest employers, engaging over 2.3 million people in Ghana as of 2022.[50] These sectors are seeing growth: for example, retail trade expanded by about 3.9% year-on-year in 2023, while transport services grew 4.6% in the same period.[46] Continued investments in transport infrastructure and participation in regional trade are expected to further boost logistics and trade activities.

3.2. Impacts of heat stress on work capacity

3.2.1. Link between heat stress, work intensity, and capacity to perform work

The interplay between heat stress and work intensity is a critical factor in determining an individual's capacity to perform work. High work intensity exacerbates the physiological effects of heat, leading to quicker onset of fatigue, slower work pace, and increased safety risks. Understanding this relationship is essential for developing effective workplace policies and protective measures, such as adjusted work-rest cycles and hydration protocols, which aim to mitigate these impacts and maintain productivity even in challenging environmental conditions.

When the body cannot remove enough heat to ensure that its internal temperature remains stable, this leads to a range of adverse physiological responses.[42] These responses become particularly significant in occupational settings where physical work is required.

Heat stress and the human body

When exposed to intense heat, the human body struggles to maintain its normal internal temperature. As WBGT levels increase, the body directs more blood flow to the skin in an effort to cool down.[43] This physiological adjustment places additional strain on the cardiovascular system, leading to fatigue, reduced cognitive function, and an increased risk of heat-related illnesses such as heat exhaustion and heat stroke.[43,56]

Work intensity and metabolic heat production

The physical effort required for high-intensity work naturally produces metabolic heat.[43,57] When this internal heat generation combines with external (environmental) heat stress, the body's cooling mechanisms can be overwhelmed.[43] Workers engaged in high-intensity activities are, therefore, at a greater risk of experiencing the negative effects of heat. As the body becomes stressed by the combined internal and external heat loads, it responds by slowing down physical work as a protective mechanism. This slowdown is called "behavioural thermoregulation"[44] and it is a key factor in the observed loss of work time and, therefore, productivity.[58]

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[54] Statista.com (2023). Contribution of travel and tourism to gross domestic product (GDP) in Ghana from 2019 to 2023. https://www.statista.com/statistics/1278510/contribution-of-tourism-to-gdp-in-ghana. Accessed: 6/12/2024.
[55] The World Bank in Ghana. https://www.worldbank.org/en/country/ghana/overview. Accessed: 6/12/2024.
[56] Kenny G.P., Wilson T.E., Flouris A.D., Fujii N. (2018). Heat exhaustion. Handbook of Clinical Neurology; 157: 505-529.
[57] Poulianiti K.P., Havenith G., Flouris A.D. (2019). Metabolic energy cost of workers in agriculture, construction, manufacturing, tourism, and transportation industries. Industrial Health; 57(3): 283-305.
[58] Ioannou L.G., Tsoutsoubi L., Samoutis G., Bogataj L.K., Kenny G.P., Nybo L., Kjellstrom T., Flouris A.D. (2017). Time-motion analysis as a novel approach for evaluating the impact of environmental heat exposure on labor loss in agriculture workers. Temperature; 4(3): 330-340.

Loss of capacity to perform work

Reduced capacity to perform work under high heat stress is not only a matter of slower movement; it also includes reduced work output[58,59] and increased error rates.[60] This occurs because workers should take more frequent breaks, reduce their pace, or even stop working to avoid heat-related health risks.[61] The cumulative effect of these adjustments is a measurable loss in work time and, therefore, productivity, as well as increased risks of accidents and long-term health impacts.[41,59]

3.2.2. Projected loss of work capacity due to rising heat stress from climate change

The impact of heat stress on the capacity to perform work in Ghana was estimated using a response function for workability, based on previous methods.[62] The estimated work capacity loss in Ghana's agricultural, construction, manufacturing, mining and quarrying, services, as well as transport and trade sectors are illustrated in Figures 8-10. The estimates were computed separately for different work intensity levels (high, moderate, and low) for the historical reference period (1985-2014) and up to 2100 based on the different SSPs. Also, they show work capacity loss during a given year as well as work capacity loss due to climate change (i.e., calculated as a change from the baseline historical period 1985-2014).

During the historical period, work capacity losses in **agriculture** and **construction** (Figure 8) fluctuated around 50-55% in high-intensity work, 33-40% in moderate-intensity work, and 19-25% in low-intensity work. Climate change will lead to significant work capacity losses beyond the levels observed in the historical period. Under SSP1-2.6 and SSP2-4.5, climate change will cause further work capacity losses of 10-20% in high-intensity work, 15-25% in moderate-intensity work, and 15-28% in low-intensity work, reflecting significant impacts despite strong climate change mitigation. In SSP3-7.0 and SSP5-8.5, climate change will lead to additional work capacity losses reaching 30% in high-intensity work and 50% in low-intensity work by 2100, reflecting the severe impact of climate change and heat stress on work capacity.

The paradox of work intensity and extreme heat stress

The data shown in Figure 8 indicates that work capacity losses due to climate change will be highest in low-intensity work and lowest in high-intensity work in agriculture and construction. This is explained by the extreme heat stress experienced by agriculture and construction workers in Ghana, which caused 55% work capacity loss during high-intensity work in the historical period, and this will reach nearly 90% by 2100 in the high-emissions scenario – an increase of 30 percentage points. On the other hand, the heat stress experienced by workers performing low-intensity work is much less significant, leading to "only" 25% work capacity losses during the historical period and increasing to 75% by 2100 in the high-emissions scenario – an increase of 50 percentage points. Field data[58,59] shows that people working under extreme heat stress are already near their physiological limit and, therefore, any further warming beyond current levels will have less of an impact, compared to individuals performing work at lower levels of heat stress.

[59] Ioannou L.G., Tsoutsoubi L., Mantzios K., et al. (2025). The impact of workplace heat and cold on work time loss. Journal of Occupational and Environmental Medicine; doi: 10.1097/JOM.0000000000003332.
[60] Ioannou L.G., Mantzios K., Tsoutsoubi L., Panagiotaki Z., Kapnia A.K., Ciuha U., Nybo L., Flouris A.D., Mekjavic I.B. (2021). Effect of a simulated heat wave on physiological strain and labour productivity. International Journal of Environmental Research and Public Health; 18(6): 3011.
[61] Flouris A.D., Ioannou L.D., Dinas P.C., et al. (2019). Assessment of occupational heat strain and mitigation strategies in Qatar – Key Findings. International Labour Organization, United Nations: Doha, Qatar.
[62] García-León D., Casanueva A., Standardi G., Burgstall A., Flouris A.D., Nybo L. (2021). Current and projected regional economic impacts of heatwaves in Europe. Nature Communications; 12(1): 5807.

In **manufacturing**, **mining and quarrying** (Figure 9), **services**, as well as **transportation and trade** (Figure 10), work capacity losses fluctuated around 16-22% in high-intensity work, 6-10% in moderate-intensity work, and 1-3% in low-intensity work. Climate change will lead to important work capacity losses beyond the levels observed in the historical period. Under SSP1-2.6 and SSP2-4.5, climate change will cause further work capacity losses of 8-20% in high-intensity work, 5-12% in moderate-intensity work, and 2-8% in low-intensity work, reflecting significant impacts despite strong climate change mitigation. In SSP3-7.0 and SSP5-8.5, climate change will lead to additional work capacity losses reaching 25% in low-intensity work and surpassing 40% in high-intensity work by 2100, suggesting significant heat stress impacts and underscoring the impact of high heat exposure and the need for adaptation measures.

Overall, the key findings of this analysis are as follows:

- **Intensity matters:** work capacity losses are directly linked to work intensity, with high-intensity work across all industries facing the greatest absolute losses in work capacity, whereas low-intensity jobs will see the highest productivity reductions by 2100 under all scenarios. As explained in the above box, people working in high-intensity jobs in Ghana are already near their physiological limit and, therefore, any further warming beyond current levels will have less of an impact, compared to individuals performing work at lower work intensities.
- **Vulnerability is unequal:** agriculture and construction show the highest work capacity losses due to increased heat stress from climate change, reaching as high as 90% by century end. Manufacturing, mining and quarrying, services, transportation, and trade are also heavily impacted, but at a lesser degree.
- **Scenario divergence:** under more optimistic scenarios (SSP1-2.6, SSP2-4.5), work capacity losses remain relatively low across all intensity levels. However, in scenarios where climate action is delayed or absent (SSP3-7.0, SSP5-8.5), work capacity losses increase significantly, particularly for high-intensity work.
- **Long-term trends:** regardless of the SSP, work capacity losses generally increase towards the latter half of the century, reflecting the long-term effects of climate change on work capacity in Ghana.

This analysis emphasizes the need for targeted adaptation strategies, particularly for high-intensity labour, to mitigate work capacity losses in the context of increasing heat levels and climate change impacts.

Figure 8. Average work capacity loss (%) in Ghana during high- (top), moderate- (middle), and low- (bottom) intensity work in agriculture (left graphs) and construction (right graphs) during the reference historical period (1985-2014) and until 2100 across the different SSPs. Vertical axes in each graph show work capacity loss during a given year (right hand side axis) and work capacity loss due to climate change, calculated as a change from the baseline historical period 1985-2014 (left hand side axis). Shaded areas represent 95% confidence intervals.

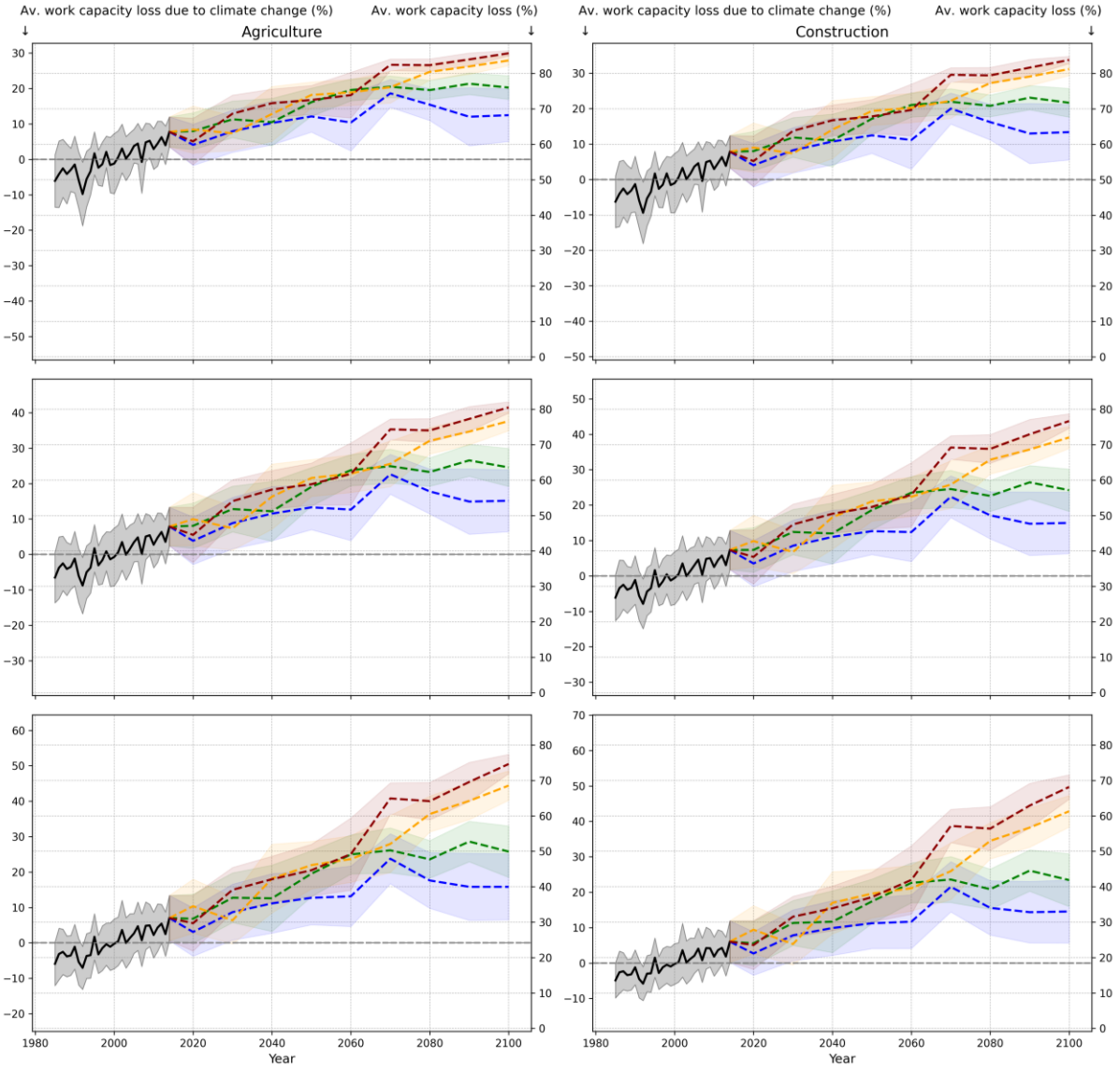


Figure 9. Average work capacity loss (%) in Ghana during high- (top), moderate- (middle), and low- (bottom) intensity work in manufacturing (left graphs) as well as mining and quarrying (right graphs) during the reference historical period (1985-2014) and until 2100 across the different SSPs. Vertical axes in each graph show work capacity loss during a given year (right hand side axis) and work capacity loss due to climate change, calculated as a change from the baseline historical period 1985-2014 (left hand side axis). Shaded areas represent 95% confidence intervals.

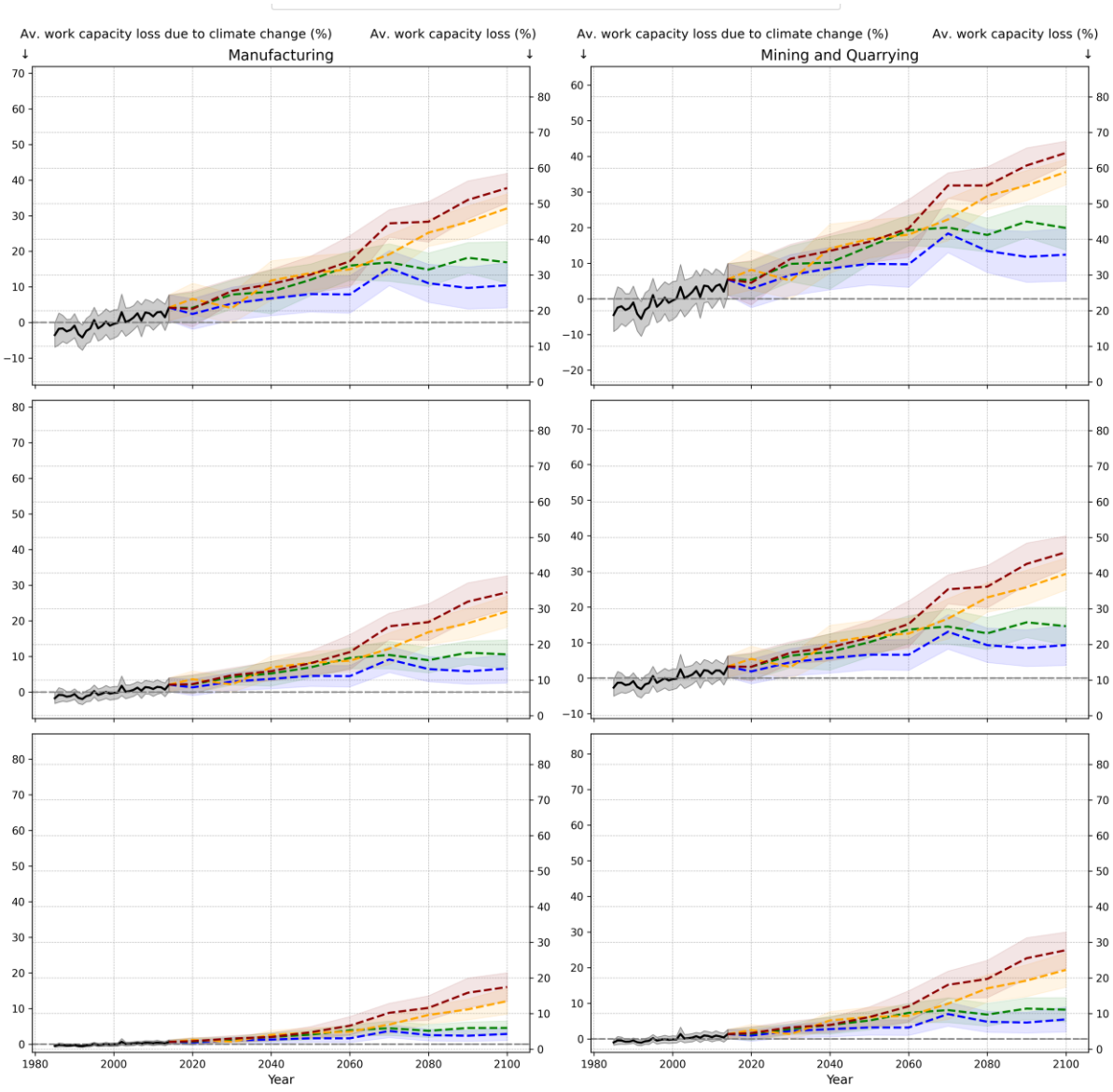
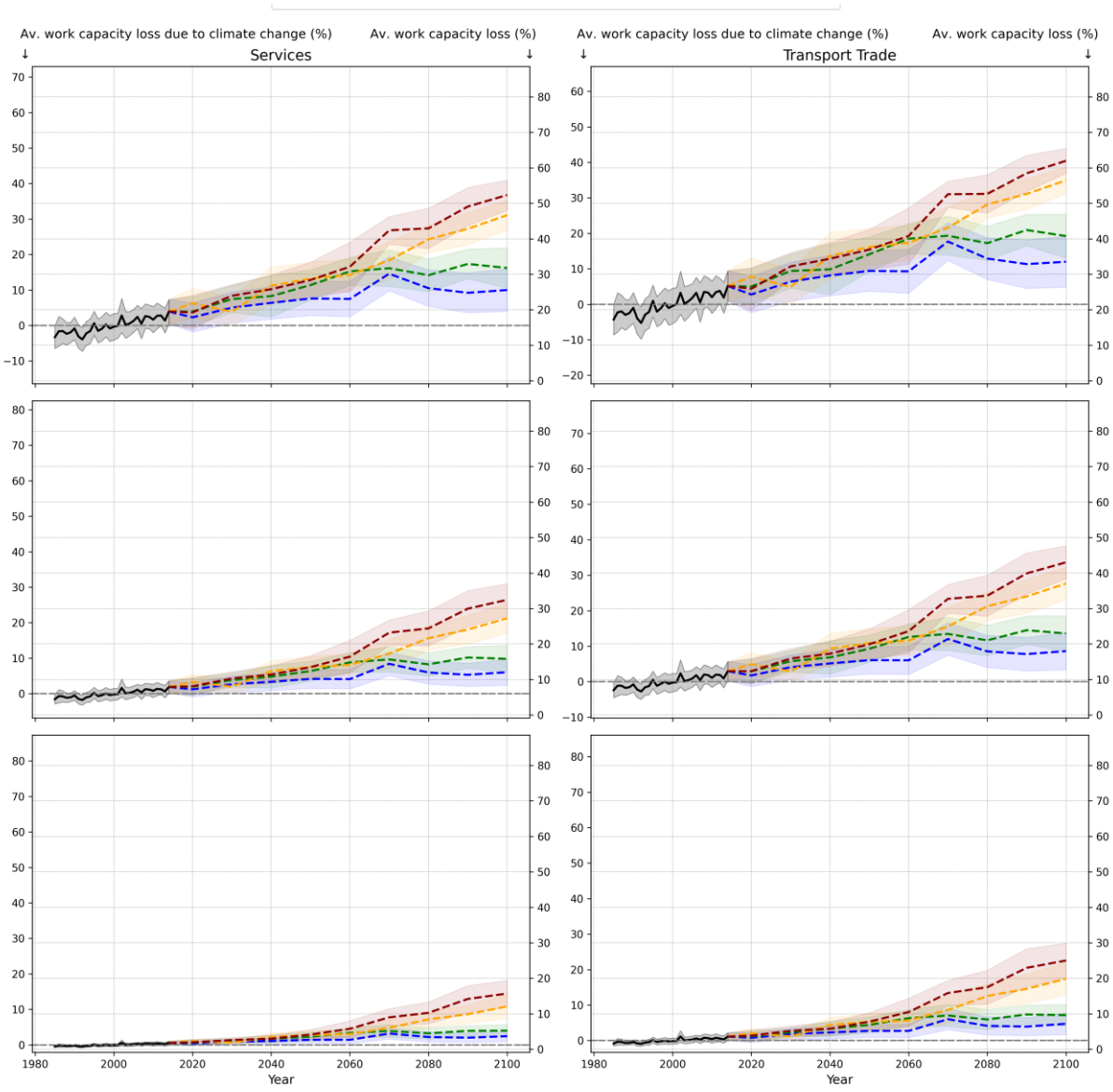


Figure 10. Average work capacity loss (%) in Ghana during high- (top), moderate- (middle), and low- (bottom) intensity work in services (left graphs) as well as transportation and trade (right graphs) during the reference historical period (1985-2014) and until 2100 across the different SSPs. Vertical axes in each graph show work capacity loss during a given year (right hand side axis) and work capacity loss due to climate change, calculated as a change from the baseline historical period 1985-2014 (left hand side axis). Shaded areas represent 95% confidence intervals.



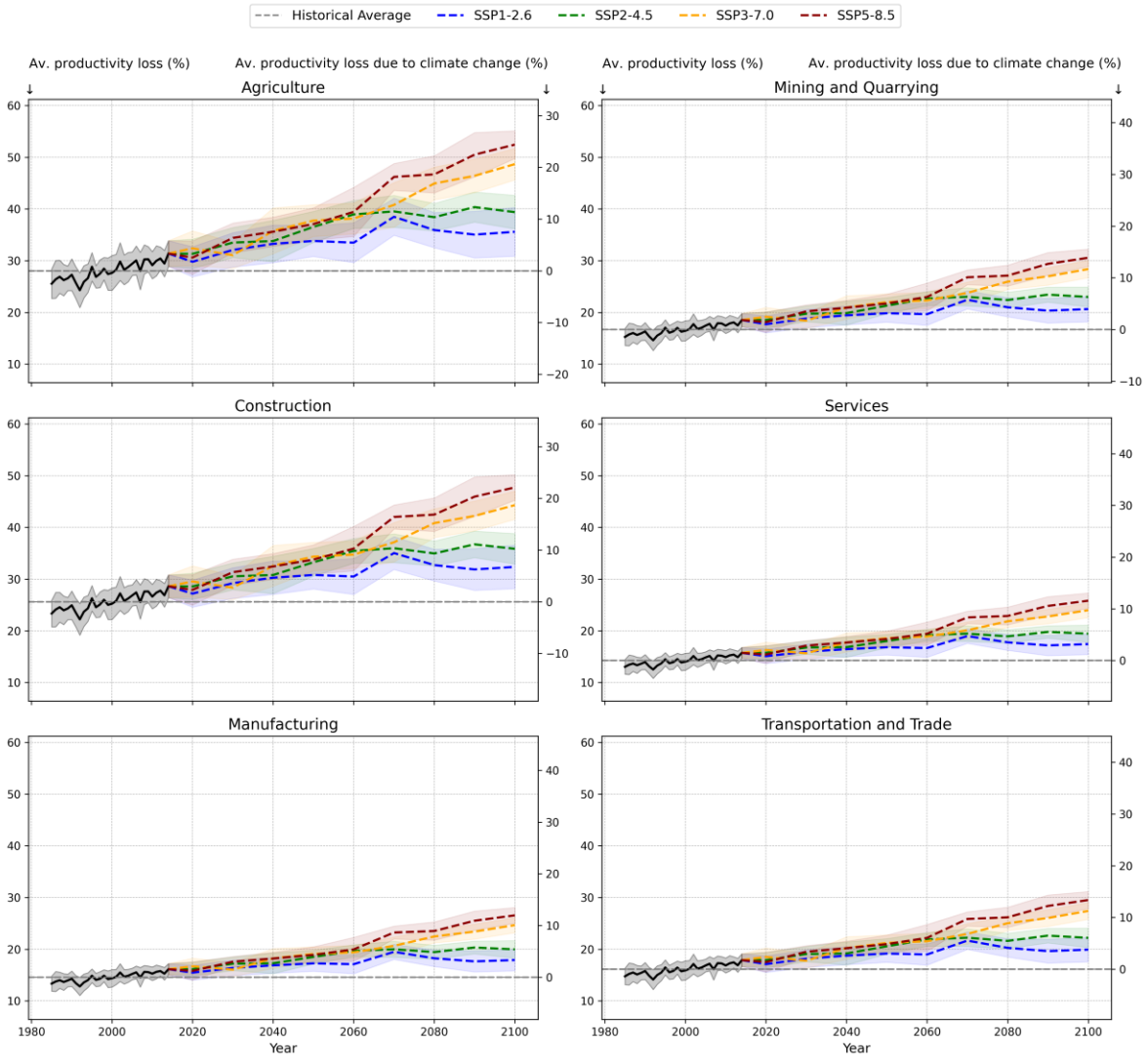
4. Loss of productivity by sector of activity

Productivity loss was estimated using a recently introduced response function linking WBGT and the time that workers allocate to work- and non-work-related activities during a typical work shift. The response function has been developed based on field studies (including studies from the ILO) that performed detailed monitoring of >600 of work shifts from different industries across multiple countries in Central America, Central and South Europe, as well as the Middle East.[41,59,60,61] This methodology provides robust estimates of productivity loss due to heat stress for the average, experienced, and acclimatized worker who performs their typical daily shift.

The estimated productivity loss by sector due to climate change and heat stress under current and projected conditions is illustrated in Figure 11. In **agriculture** and **construction**, productivity loss due to heat stress fluctuated between 24% and 31%, during the historical period. By 2100, under SSP1-2.6 and SSP2-4.5, productivity loss is expected to further increase by 10% due to climate change, reflecting relatively mild impacts due to climate change mitigation. Under SSP3-7.0 and SSP5-8.5, climate change will lead to increases in productivity loss compared to the average year of the reference historical period, reaching as high as 25% toward the end of the century. Agriculture and construction are thereby particularly vulnerable sectors to productivity loss due to climate change.

In **manufacturing**, **mining and quarrying**, **services**, as well as **transportation** and **trade**, productivity loss due to heat stress remained stable at about 15% to 18% during the historical period. Under SSP1-2.6 and SSP2-4.5, climate change is anticipated to further increase productivity loss by 3-5% by the end of the century. This will be higher under SSP3-7.0 and SSP5-8.5, resulting in additional productivity loss of up to 14% in these scenarios by 2100, compared to the average year within the reference period.

Figure 11. Average productivity loss in Ghana in agriculture (top left), construction (middle left), manufacturing (bottom left), mining and quarrying (top right), services (middle right), as well as transportation and trade (bottom right) during the reference historical period (1985-2014) and until 2100 across the different SSPs. Vertical axes in each graph show productivity loss during a given year (left hand side axis) and productivity loss due to climate change, calculated as a change from the baseline historical period 1985-2014 (right hand side axis). Shaded areas represent 95% confidence intervals.



5. Economic and labour market impacts

5.1. Current economic impacts

Heat stress affects not only individual workers but also has far-reaching implications for national economies. When workers are exposed to high levels of heat, they tend to slow down, take more frequent breaks, or may even be unable to work at all – all of which reduce the effective work time. This reduction in labour input at the worker level (which includes all types of labour including managerial jobs) accumulates into the loss of productivity in specific sectors of the economy (agriculture, construction etc.) and, in aggregate, directly translates into lower economic output, which is reflected in a decrease in GDP. Essentially, economic production relies on the total available work hours, and when those hours diminish due to heat stress, the overall contribution of the workforce to production is reduced.

The analysis presented in Section 4 estimates the number of work hours lost due to heat stress caused by climate change across key economic sectors. These lost work hours indicate a lower effective labour input compared to the baseline historical period 1985-2014. By applying industry- and location-specific multipliers that account for each sector's share of the economy, the corresponding loss in GDP can be estimated. These estimates unravel the GDP lost due to climate change for the present (i.e., 2023), calculated as the change in heat stress levels from the reference historical period (1985-2014), while considering the associated fluctuations in GDP and industry-specific contribution to GDP. The analysis can be then expanded to provide estimates for 2040 and 2060 according to the population, socioeconomic, and governance contexts of each SSP. The methodology used for these analyses is described in Annex 1.

The findings from the analysis on the economic impacts of rising heat stress due to climate change demonstrate that Ghana lost 8.6 billion USD more in 2023 compared to the average year during the reference historical period (1985-2014) (Table 2). The distribution of the GDP loss (in million USD) due to climate change across the country is illustrated in Figure 12.

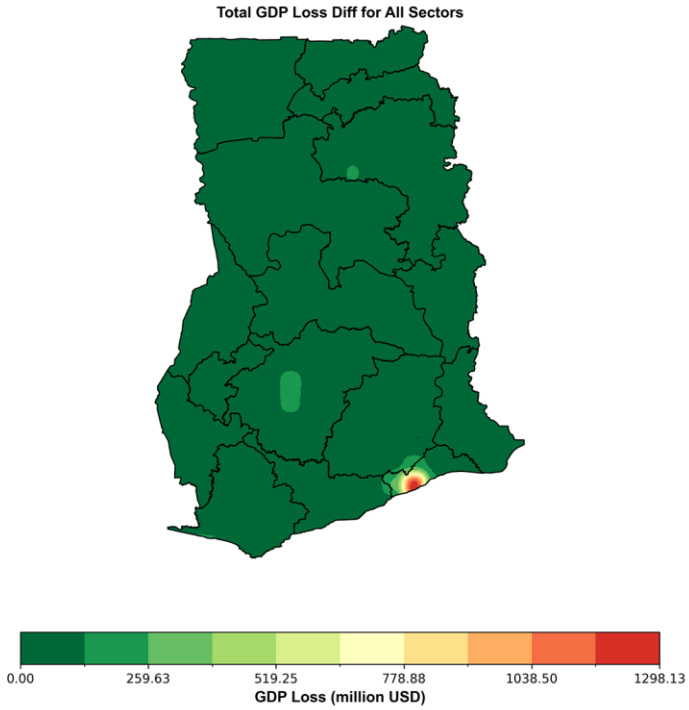
The map indicates a clear hotspot of economic loss around Accra in the southern coastal zone. This pattern suggests that heat stress exerts the highest financial toll where population density and economic activities, particularly formal employment, are concentrated. Even modest temperature rises in Greater Accra can generate substantial productivity losses, while more sparsely populated regions remain in lower absolute loss brackets due to their smaller share of national GDP.

Table 2. Change in the contribution of each sector to GDP due to rising workplace heat stress caused by climate change, between 2023 and the reference historical period 1985-2014.

Sector	**Change in GDP** *(M USD)**	*(distribution; %)*
Agriculture	-3,278.3	37.9
Construction	-671.8	7.8
Manufacturing	-537.4	6.2
Mining and Quarrying	-1,012.7	11.7
Services	-1,971.1	22.8
Transport and Trade	-1,169.9	13.6
Total GDP change	-8,641.2	

* million USD (fixed 2015 prices), with negative values indicating a GDP reduction compared to the baseline historical period 1985-2014.

Figure 12. GDP loss across Ghana due to rising workplace heat stress caused by climate change, between 2023 and the baseline historical period 1985-2014.



Overall, the map shows that climate change has already reduced Ghana's GDP through workplace heat in 2023 when compared with the 1985 to 2014 baseline. Losses are not uniform. They are concentrated in the Greater Accra area around Accra and Tema. This is the only clear national hotspot and reaches about 1.3 billion US dollars in lost output more than the average year during the historical period. The capital region concentrates services, trade, transport, and manufacturing. When heat cuts work time and slows industrial activity, the absolute loss is largest where value added and employment are densest. Coastal conditions and the urban heat island likely add to exposure during the warmest hours, which amplifies the effect.

Importantly, lower values elsewhere do not mean low risk. In many rural districts the absolute loss is small because the economic base is smaller. The impact on workers and firms can still be meaningful, especially in agriculture and construction where tasks are outdoors and physically demanding.

The policy message is clear. Protect workers and firms in the Accra and Tema corridor and other urban hubs, as well as strengthen heat management in rural sectors. Measures such as risk assessment, work rest cycles, access to cooling, shade, and flexible hours can limit growing losses and support decent and productive work.

5.1.1. Sectoral contribution to current GDP loss

The analysis presented in Section 5.1 was also used to estimate the impact of climate change on each sector of economic activity. Specifically, the analysis estimated the change in the contribution of each sector to overall GDP due to rising workplace heat stress caused by climate change, between 2023 and the reference historical period (1985-2014). The methodology used for this analysis is described in Annex 1.

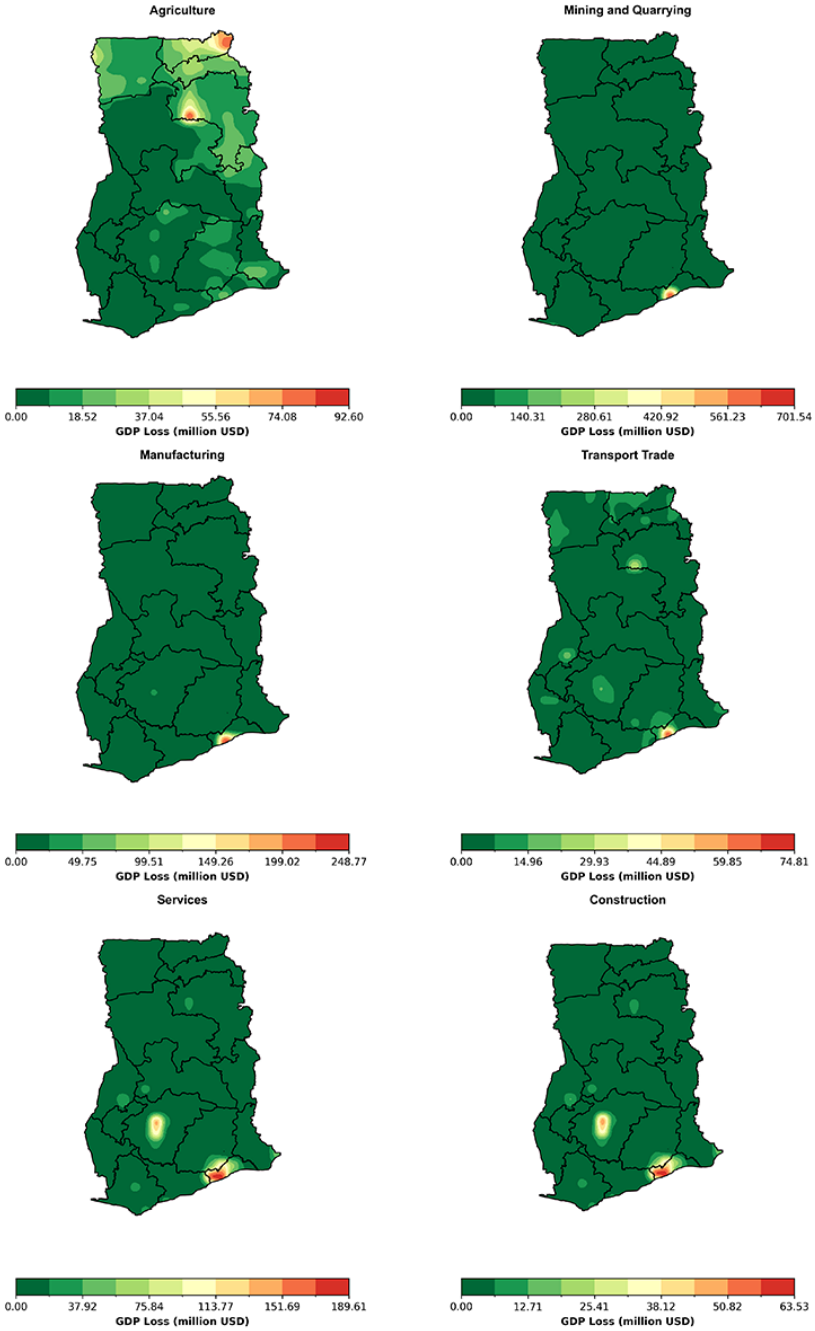
The impact of rising workplace heat stress due to climate change on each sector of economic activity is shown in Table 2. The GDP losses in the agriculture sector far outweigh those from all other sectors, representing 37.9% of the additional GDP losses compared to an average year during the historical period. Services are also heavily impacted, with nearly 2 billion more USD lost due to heat stress during 2023 in relation to an average year during the historical period (Table 2). Transport and trade as well as mining and quarrying are also heavily impacted, representing 13.6% and 11.7% of the additional GDP losses compared to an average year during the historical period (Table 2).

The regional distribution of the impact of rising workplace heat stress due to climate change on each sector of economic activity is illustrated geographically in Figure 13. A technical note is warranted: because sector sizes differ markedly, the figure uses sector-specific GDP ranges to preserve spatial detail. Cross-map comparisons should therefore focus on patterns and locations of loss rather than colour intensity alone. The analysis shows that losses in services are centered on Greater Accra and spill into nearby districts, with a second cluster around Kumasi. This mirrors where service activity and employment are concentrated and where heat during peak hours disrupts work. Construction follows a similar pattern, with hotspots in Accra and Kumasi where outdoor worksites and urban heat intensify exposure. Manufacturing losses peak along the south-eastern coast near the main port and industrial zones and appear around Kumasi as well, reflecting warm indoor workplaces with partial cooling. Transport and trade show losses along major logistics nodes and corridors that link the coast to interior hubs, including Accra and Kumasi. These activities are hard to reschedule and often occur in exposed loading areas, so heat translates quickly into time lost and lower throughput.

Agriculture shows a different geography. Losses cluster in the northern savannah and in pockets around the Volta basin and parts of the south-west. The sector's heavy outdoor work makes it sensitive to high WBGT conditions even when absolute GDP per km^2 is smaller than in urban services. Mining and quarrying losses are site specific, with a clear focus in the south-west and selected operations elsewhere. While the national total is modest, the local economic effect can be large.

Taken together, the strongest absolute impacts fall where economic activity and workers are most concentrated, especially in Greater Accra and along main transport and industrial corridors. Rural and extraction areas also show meaningful losses. These patterns point to priority locations for heat risk management to limit further GDP decline.

Figure 13. GDP loss across Ghana due to rising workplace heat stress caused by climate change, between 2023 and the baseline historical period 1985-2014, in each sector of economic activity. Note: due to the dominance of the service sector in Ghana's economy, it was not possible to maintain a constant range of GDP loss across all maps as the smaller size of the other sectors would prohibit an efficient illustration of the data.



5.2. Future economic impacts

The projected impact of rising workplace heat stress due to climate change on total and sectoral GDP during 2040 and 2060 across the different SSPs is presented in Table 3. Ghana's macro-economic exposure to rising workplace heat stress is set to intensify between 2040 and 2060, with outcomes highly sensitive to global

emissions scenarios. Even on a Paris-aligned trajectory (SSP1-2.6), heat-related productivity losses will reduce GDP by about 13.1% and 14.8% more in 2040 and 2060, respectively, relative to the losses during the average year within the 1985-2014 baseline. This is equal to an annual loss of 23.2 billion USD in 2040 and 100.2 billion USD in 2060. Under a "middle-of-the-road" scenario (SSP2-4.5), the contraction deepens from 13.4% (19 billion USD) in 2040 to 16.5% (82.3 billion USD) in 2060. Should fossil-fuel development continue unabated (SSP5-8.5), rising workplace heat stress could cut 18% (165.2 billion USD) off annual national output by 2060, eliminating the cumulative GDP value of several medium-sized manufacturing subsectors.

The sectoral pattern is uneven but consistent across pathways. Services, the backbone of the Ghanaian economy, bears most of the losses: 4.8% (8.6 billion USD) more losses in 2040 under SSP1-2.6 compared to the historical period, rising to 6.4% (58.6 billion USD) in 2060 under SSP5-8.5. Manufacturing as well as mining and quarrying absorb steady declines that deepen from 4 billion USD (SSP1-2.6, 2040) to 27 billion USD (SSP5-8.5, 2060). Similarly, agriculture, construction, as well as transport and trade will record rising losses from 2-3 billion USD in 2040 under SSP1-2.6 to 20.5 billion USD in 2060 under SSP5-8.5.

Three policy conclusions follow. First, the steep scenario gradient confirms that ambitious global mitigation (SSP1-2.6) could avert 3.16 percentage points of GDP loss by 2060 (about 65.1 billion USD in 2060), relative to SSP5-8.5. Second, domestic adaptation should prioritise heat-proofing the services industry, particularly retail, hospitality, and public administration, where the absolute loss is greatest (Infographic 1). This implies accelerated investment in efficient cooling, urban heat-island management and flexible work scheduling. Third, sector-specific labour regulations should anticipate that expansion in services, manufacturing, and construction will intensify exposure to workplace heat stress. Therefore, integrating heat stress thresholds into building codes as well as social-protection schemes will be critical. Anchoring these measures in Ghana's forthcoming National Adaptation Plan and Decent Work Country Programme will help safeguard both competitiveness and worker welfare as temperatures rise.

Infographic 1. Sectoral GDP benefits of implementing in Ghana the decent work and sustainable development goals as described in SSP1-2.6, particularly in relation to workplace heat stress (calculated as differences between SSP5-8.5 and SSP1-2.6).

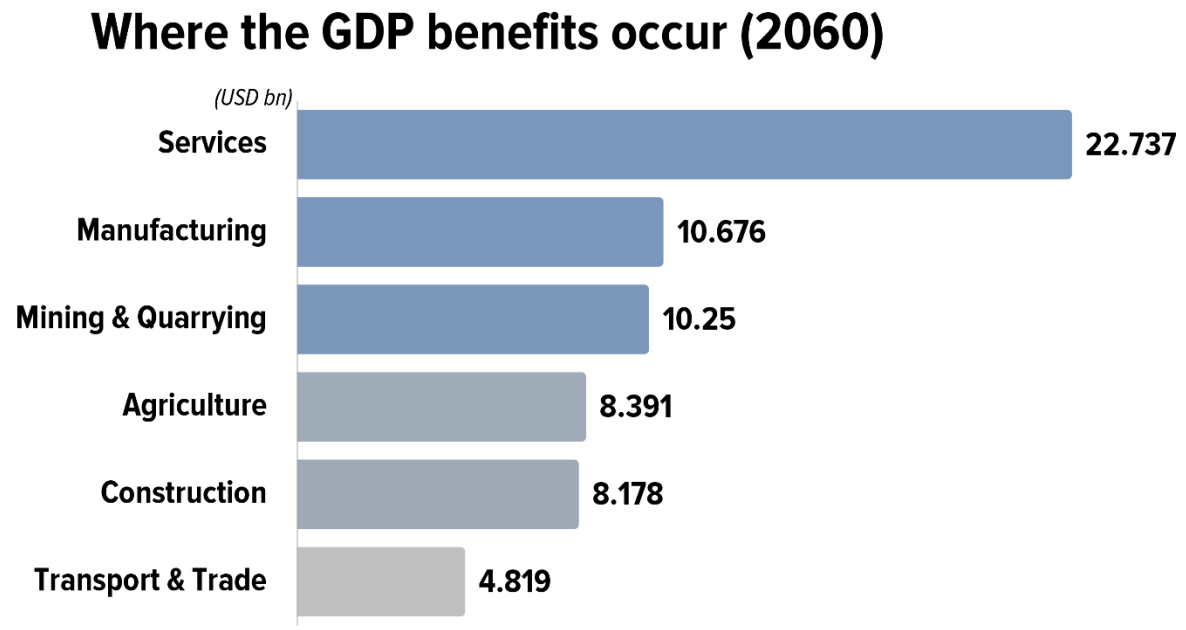


Table 3. Annual impact of rising workplace heat stress caused by climate change on GDP in Ghana during 2040 and 2060 across different SSPs, compared to the baseline historical period 1985-2014.

		Change in GDP			
		2040		**2060**	
		(M USD)[1]	*(%)*	*(M USD)*[1]	*(%)*
Agriculture	SSP1-2.6	-1,882.4	-1.06	-11,884.3	-1.76
	SSP2-4.5	-1,215.9	-0.86	-10,084.9	-2.03
	SSP3-7.0	-657.3	-0.59	-4,782.4	-1.70
	SSP5-8.5	-2,918.3	-1.37	-20,275.4	-2.21
Construction	SSP1-2.6	-2,923.4	-1.65	-12,228.2	-1.81
	SSP2-4.5	-2,448.5	-1.73	-10,006.7	-2.01
	SSP3-7.0	-1,877.6	-1.67	-5,708.3	-2.03
	SSP5-8.5	-3,901.1	-1.84	-20,405.9	-2.22
Manufacturing	SSP1-2.6	-3,978.3	-2.24	-16,672.5	-2.46
	SSP2-4.5	-3,325.1	-2.35	-13,501.8	-2.71
	SSP3-7.0	-2,533.0	-2.26	-7,516.9	-2.68
	SSP5-8.5	-5,279.6	-2.48	-27,348.8	-2.97
Mining and Quarrying	SSP1-2.6	-4,014.6	-2.26	-15,917.0	-2.35
	SSP2-4.5	-3,467.4	-2.45	-13,057.7	-2.62
	SSP3-7.0	-2,655.7	-2.37	-7,279.2	-2.59
	SSP5-8.5	-5,217.7	-2.46	-26,167.4	-2.85
Services	SSP1-2.6	-8,587.2	-4.84	-35,878.3	-5.30
	SSP2-4.5	-7,091.5	-5.00	-29,292.5	-5.89
	SSP3-7.0	-5,517.8	-4.92	-16,587.6	-5.91
	SSP5-8.5	-11,373.7	-5.35	-58,615.7	-6.37
Transport and Trade	SSP1-2.6	-1,801.4	-1.02	-7,590.5	-1.12
	SSP2-4.5	-1,473.2	-1.04	-6,331.2	-1.27
	SSP3-7.0	-1,138.7	-1.01	-3,513.9	-1.25
	SSP5-8.5	-2,400.0	-1.13	-12,409.6	-1.35
TOTAL	SSP1-2.6	-23,187.4	-13.08	-100,170.9	-14.80
	SSP2-4.5	-19,021.6	-13.41	-82,274.9	-16.54
	SSP3-7.0	-14,380.1	-12.82	-45,388.3	-16.16
	SSP5-8.5	-31,090.4	-14.63	-165,222.8	-17.97

[1] million USD, fixed 2015 prices.

SSP: shared socioeconomic pathway; negative values indicate a GDP reduction compared to the baseline historical period 1985-2014.

5.3. Current labour market impacts

When workers experience heat stress, they are forced to reduce their output either by working at a slower pace or by taking more frequent breaks. Over time, this reduction in effective work time accumulates and it is essential to translate the reductions in working hours into a metric that can be readily understood. The most appropriate metric is full-time equivalent (FTE) job losses, a standard indicator of economic and labour market impact. In the case of heat stress, FTE job losses describe the reduction in the number of full-time jobs that could have been sustained under optimal working conditions. This methodology allows quantifying the impact of workplace heat stress on labour markets in a standardized and comprehensible manner, facilitating comparisons across industries and informing policy decisions aimed at mitigating these adverse effects.

The conversion of lost working hours into FTE job losses is based on a standard calculation of annual working hours per worker. It is assumed that a worker takes a minimum of 14 days of leave per year. Considering a typical work schedule of 5 days per week and 8 hours per day, the total potential working hours per year are calculated as:

$$\text{Annual Working Hours} = (365\text{-}14) \times \frac{5}{7} \times 8 \approx 2006 \text{ hours}$$

The FTE job losses per industry are calculated by comparing the available work hours against the reduced work hours resulting from workplace heat stress (provided in Section 4). The difference between the total potential working hours (2006 hours per year) and the actual hours worked (after accounting for the hours lost due to workplace heat stress) represents the deficit in labour input. This deficit is then divided by the standard annual working hours (2006 hours) to obtain the number of FTE jobs lost.

The analysis used data for 2023 to describe the current impact of rising heat stress due to climate change on Ghana's labour market. Thus, estimates were expressed as the change between 2023 and the reference historical period 1985-2014, while considering the associated fluctuations in GDP.

The findings provided in Table 4 show that the impact of climate change on Ghana's labour market is significant, with over 345 thousand more jobs lost due to workplace heat stress during 2023 compared to the average year during the historical period. Over 66% of job losses are concentrated in agriculture, 21% occur in services, as well as about 5%, 4%, and 3% in construction, manufacturing, as well as transport and trade, respectively (Table 4 and Infographic 2). The analysis also reflects a seasonal pattern where 36% of the impacts occur in Q1, the part of the year when heat spreads to the coastal south regions, affecting major industrial nodes, including Accra and Kumasi (Section 2.3; Figures 2-3).

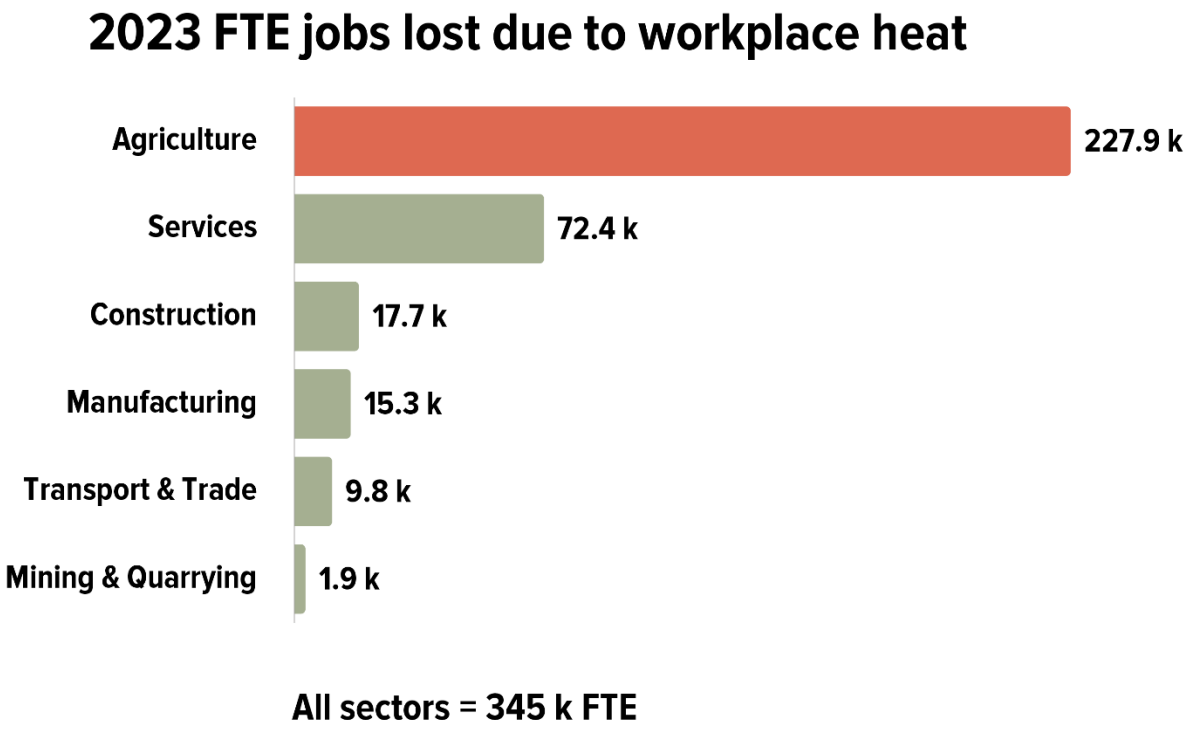
Table 4. Quarterly and annual impact of rising heat stress due to climate change on full-time equivalent jobs lost (proxied from work hours lost) in each sector of economic activity and across the entire economy in Ghana, calculated as the change between 2023 and the reference historical period 1985-2014 (negative values indicate losses vs reference).

Sector	Period	Available Work Hours (n)	Change in Work Hours		Change in Jobs (FTE)
			(n)	(% FTE)	
Agriculture	Q1	2,756,561,240	-177,759,800	-6.45	-88,614
	Q2	2,788,429,000	-136,639,142	-4.90	-68,115
	Q3	2,820,296,760	-76,069,322	-2.70	-37,921
	Q4	2,820,296,760	-66,740,738	-2.37	-33,271
	Year	11,185,583,760	-457,209,001	-4.09	-227,921
Construction	Q1	342,507,871	-9,892,752	-2.89	-4,932
	Q2	346,467,500	-10,934,106	-3.16	-5,451
	Q3	350,427,129	-7,361,164	-2.10	-3,670
	Q4	350,427,129	-7,354,521	-2.10	-3,666
	Year	1,389,829,629	-35,542,544	-2.56	-17,718
Manufacturing	Q1	602,502,651	-9,021,191	-1.50	-4,497
	Q2	609,468,000	-9,524,771	-1.56	-4,748
	Q3	616,433,349	-6,689,121	-1.09	-3,335
	Q4	616,433,349	-5,424,437	-0.88	-2,704
	Year	2,444,837,349	-30,659,520	-1.25	-15,284
Mining and Quarrying	Q1	71,886,443	-997,030	-1.39	-497
	Q2	72,717,500	-1,236,112	-1.70	-616
	Q3	73,548,557	-904,563	-1.23	-451
	Q4	73,548,557	-705,488	-0.96	-352
	Year	291,701,057	-3,843,193	-1.32	-1,916
Services	Q1	2,604,738,417	-46,135,271	-1.77	-22,999
	Q2	2,634,851,000	-43,440,105	-1.65	-21,655
	Q3	2,664,963,583	-29,407,613	-1.10	-14,660
	Q4	2,664,963,583	-26,200,827	-0.98	-13,061
	Year	10,569,516,583	-145,183,815	-1.37	-72,375
Transport and Trade	Q1	257,350,351	-7,199,821	-2.80	-3,589
	Q2	260,325,500	-5,871,171	-2.26	-2,927
	Q3	263,300,649	-3,622,229	-1.38	-1,806
	Q4	263,300,649	-2,944,933	-1.12	-1,468
	Year	1,044,277,149	-19,638,155	-1.88	-9,790
TOTAL	Q1	6,635,546,974	-251,005,864	-3.78	-125,128
	Q2	6,712,258,500	-207,645,407	-3.09	-103,512
	Q3	6,788,970,026	-124,054,012	-1.83	-61,841
	Q4	6,788,970,026	-109,370,944	-1.61	-54,522
	Year	26,925,745,526	-692,076,228	-2.57	-345,003

n: number; FTE: full-time equivalent.

These results highlight the urgent need for adaptive policies, such as regulated work-rest cycles, access to cooling measures, and the integration of heat mitigation into occupational safety standards, to safeguard worker productivity and health in Ghana.

Infographic 2. Annual impact of rising heat stress due to climate change on full-time equivalent jobs lost (proxied from work hours lost) in each sector of economic activity and across the entire economy in Ghana, calculated as the change between 2023 and the reference historical period 1985-2014.



5.4. Future labour market impacts

Table 5 shows the annual projected labour market impacts of rising heat stress due to climate change during 2040 in each sector of economic activity and across the different SSPs, in relation to the reference historical period 1985-2014. The projected labour-time losses attributable to climate-induced heat stress grow markedly with the global emissions trajectory and are already substantial for Ghana by 2040. Model results indicate that, relative to the 1985-2014 baseline, the economy will lose the equivalent of 550 thousand full-time jobs under a low-emissions pathway (SSP1-2.6). The losses rise to nearly 753 thousand full-time jobs under SSP2-4.5 and peak at 800 thousand to 1.1 million under the high-emissions scenarios (SSP3-7.0 and SSP5-8.5). In proportional terms this represents a 6.4% contraction in total available labour time under the most optimistic scenario and 9.3% under unabated fossil-fuel development.

The burden is highly concentrated in the agriculture sector, which accounts for 379 thousand FTE annual job losses in SSP1-2.6, rising to 775 thousand in SSP3-7.0, roughly 21.3% of the sector's total labour force. Agriculture is particularly exposed given the sector's outdoor work intensity and the physiological limits of heavy manual labour in high humid-heat conditions. Services rank second, with annual job losses of 104-196 thousand FTEs across the scenario range, given that much of Ghana's retail, hospitality, and informal urban commerce occurs in environments with limited climate control. Construction follows with 27-49 thousand annual FTE job losses, suggesting that existing measures remain insufficient to offset rising WBGT. Annual losses in manufacturing as well as transport and trade are also significant, reaching up to 39 thousand FTE. Mining and quarrying show smaller, yet proportionally still significant impacts, with FTE job losses ranging from 2,919 to 4,937.

Table 5. Projected annual impact of rising heat stress due to climate change during 2040 on full-time equivalent jobs lost (proxied from work hours lost) in each sector of economic activity and across the different SSPs, calculated as the change between 2040 and the reference historical period 1985-2014.

Sector	2040	Available Work Hours (n)	Change in Work Hours		Change in Jobs (FTE)
			(n)	(% FTE)	
Agriculture	SSP1-2.6	7,310,565,823	-760,694,607	-10.41	-379,210
	SSP2-4.5		-969,360,323	-13.26	-483,230
	SSP3-7.0		-1,553,815,306	-21.25	-774,584
	SSP5-8.5		-1,020,383,044	-13.96	-508,666
Construction	SSP1-2.6	877,963,320	-54,412,838	-6.20	-27,125
	SSP2-4.5		-86,626,170	-9.87	-43,184
	SSP3-7.0		-97,889,715	-11.15	-48,798
	SSP5-8.5		-90,203,663	-10.27	-44,967
Manufacturing	SSP1-2.6	1,481,897,931	-45,346,731	-3.06	-22,606
	SSP2-4.5		-74,930,038	-5.06	-37,353
	SSP3-7.0		-78,508,501	-5.30	-39,137
	SSP5-8.5		-77,435,015	-5.23	-38,602
Mining and Quarrying	SSP1-2.6	173,618,640	-5,856,240	-3.37	-2,919
	SSP2-4.5		-9,947,568	-5.73	-4,959
	SSP3-7.0		-8,838,964	-5.09	-4,406
	SSP5-8.5		-9,904,313	-5.70	-4,937
Services	SSP1-2.6	6,676,788,189	-208,551,240	-3.12	-103,964
	SSP2-4.5		-326,572,099	-4.89	-162,798
	SSP3-7.0		-393,602,269	-5.90	-196,212
	SSP5-8.5		-353,227,172	-5.29	-176,085
Transport and Trade	SSP1-2.6	671,677,611	-29,219,654	-4.35	-14,566
	SSP2-4.5		-42,938,309	-6.39	-21,405
	SSP3-7.0		-62,174,150	-9.26	-30,994
	SSP5-8.5		-46,024,136	-6.85	-22,943
TOTAL	SSP1-2.6	17,192,511,514	-1,104,081,309	-6.42	-550,389
	SSP2-4.5		-1,510,374,507	-8.79	-752,928
	SSP3-7.0		-2,194,828,905	-12.77	-1,094,132
	SSP5-8.5		-1,597,177,343	-9.29	-796,200

SSP: shared socioeconomic pathway; n: number; FTE: full-time equivalent.

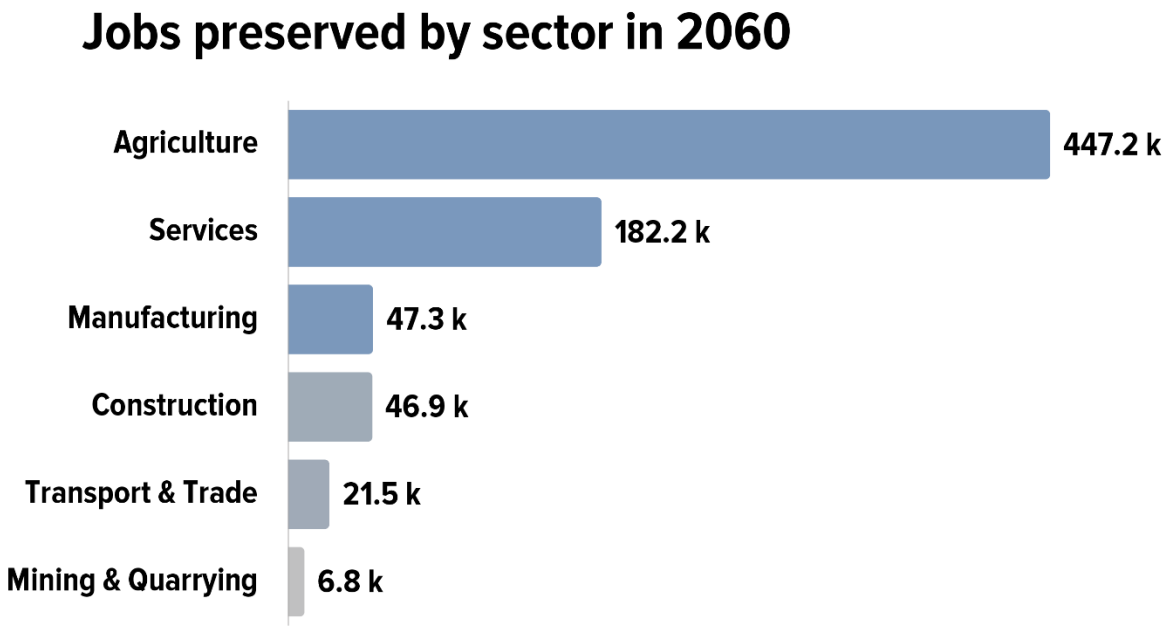
Table 6. Projected annual impact of rising heat stress due to climate change during 2060 on full-time equivalent jobs lost (proxied from work hours lost) in each sector of economic activity and across the different SSPs, calculated as the change between 2060 and the reference historical period 1985-2014.

Sector	2060	Available Work Hours (n)	Change in Work Hours (n)	Change in Work Hours (% FTE)	Change in Jobs (FTE)
Agriculture	SSP1-2.6	7,310,565,823	-824,568,090	-11.28	-411,051
	SSP2-4.5		-2,206,414,858	-30.18	-1,099,908
	SSP3-7.0		-2,644,219,556	-36.17	-1,318,155
	SSP5-8.5		-1,721,714,422	-23.55	-858,282
Construction	SSP1-2.6	877,963,320	-69,881,116	-7.96	-34,836
	SSP2-4.5		-154,953,594	-17.65	-77,245
	SSP3-7.0		-205,618,301	-23.42	-102,502
	SSP5-8.5		-164,010,062	-18.68	-81,760
Manufacturing	SSP1-2.6	1,481,897,931	-62,428,340	-4.21	-31,121
	SSP2-4.5		-131,417,810	-8.87	-65,512
	SSP3-7.0		-152,421,274	-10.29	-75,983
	SSP5-8.5		-157,278,228	-10.61	-78,404
Mining and Quarrying	SSP1-2.6	173,618,640	-8,505,062	-4.90	-4,240
	SSP2-4.5		-16,038,099	-9.24	-7,995
	SSP3-7.0		-16,632,840	-9.58	-8,292
	SSP5-8.5		-22,100,112	-12.73	-11,017
Services	SSP1-2.6	6,676,788,189	-267,763,709	-4.01	-133,481
	SSP2-4.5		-621,832,019	-9.31	-309,986
	SSP3-7.0		-810,178,367	-12.13	-403,878
	SSP5-8.5		-633,205,690	-9.48	-315,656
Transport and Trade	SSP1-2.6	671,677,611	-35,240,872	-5.25	-17,568
	SSP2-4.5		-91,251,151	-13.59	-45,489
	SSP3-7.0		-116,448,179	-17.34	-58,050
	SSP5-8.5		-78,322,581	-11.66	-39,044
TOTAL	SSP1-2.6	17,192,511,514	-1,268,387,189	-7.38	-632,297
	SSP2-4.5		-3,221,907,531	-18.74	-1,606,135
	SSP3-7.0		-3,945,518,516	-22.95	-1,966,859
	SSP5-8.5		-2,776,631,095	-16.15	-1,384,163

SSP: shared socioeconomic pathway; n: number; FTE: full-time equivalent.

Table 6 and Infographic 3 show the annual projected labour market impacts of rising heat stress due to climate change during 2060 in each sector and across the different SSPs, in relation to the reference historical period 1985-2014. The analysis shows that, by 2060, climate-driven heat stress will remove the equivalent of 0.63 to 1.97 million FTE jobs from Ghana's economy each year, depending on the global emissions pathway. Model results show that under the Paris-consistent trajectory (SSP1-2.6) Ghana will lose 633 thousand FTEs, or about 7.4% of total labour force. The toll rises sharply to 1.61 million FTEs under SSP2-4.5, 1.97 million under SSP3-7.0, and 1.38 million under SSP5-8.5, where heat cuts 16.2% more aggregate work hours compared to the average year within the historical period. Losses are highly concentrated in the agriculture sector, reflecting the impacts of heat on outdoor work and heavy manual labour in high humid-heat conditions. In 2060, agriculture will lose nearly 411 thousand FTEs in the low-emissions scenario, climbing to nearly 1.3 million FTEs in SSP3-7.0, about 36% of the sector's labour force. Services, often characterised by environments with limited climate control, ranks second, with losses escalating from 134 to over 404 thousand FTEs across the scenario range. Manufacturing, where small workshops often lack adequate cooling, will lose 31-78 thousand FTEs, while transport and trade are expected to record up to 58 thousand FTE losses. Construction shows comparable patterns (34,836-102,502 FTEs), whereas FTE losses in mining and quarrying remain lower owing to mechanisation and limited labour market size. Therefore, implementation of climate mitigation and adaptation policies will save more than 447,000 FTE jobs per year in agriculture, 182,000 FTE jobs in services, as well as about 123,000 FTE jobs in the other industrial sectors (Infographic 3).

Infographic 3. Sectoral labour market benefits of implementing in Ghana the decent work and sustainable development goals as described in SSP1-2.6, particularly in relation to workplace heat stress (calculated as differences between SSP5-8.5 and SSP1-2.6).



Policy messages emerging from the macro-economic analysis

- **Global mitigation matters**. The gap between SSP1-2.6 and SSP5-8.5 amounts to over 751 thousand saved jobs annually by 2060, underscoring the macro-labour dividend of achieving a 2 °C climate goal.

- **Agriculture and services drive vulnerability**. Targeted adaptation, such as compulsory rest-break schedules and flexible hours as well as high-efficiency cooling retrofits and heat-resilient urban design will deliver the greatest employment protection. Fiscal incentives through energy-efficiency grants or concessional credit can accelerate uptake by small enterprises.

- **Recovery could amplify exposure**. As construction and tourism rebound, additional workers will move into heat-prone roles. Embedding thermal-stress thresholds in labour codes, linking them to social-protection floors and strengthening labour-inspection capacity will be vital to safeguard productivity gains.

Integrating the above measures into Ghana's National Adaptation Plan and Decent Work Country Programme will help protect the labour market from escalating climate-driven workplace heat stress while sustaining inclusive economic growth.

6. Recommendations

6.1. Relevant international labour conventions ratified by Ghana

Ghana would be encouraged to intensify its efforts toward adapting to climate risks, particularly in safeguarding workers from extreme heat and other climate-related hazards. This vulnerability underscores the importance of adopting ILO Conventions that enhance workplace safety in evolving environmental conditions. Aligning with ILO's OSH Conventions will enable Ghana to better integrate climate-resilient practices in the workplace, helping to reduce productivity losses and health risks, particularly in heat-sensitive sectors such as agriculture and construction where workers are most exposed to heat stress.

To date, Ghana has ratified 52 ILO conventions, including 8 of the 10 fundamental ones.[63] However, key OSH conventions relevant to managing heat stress have not been ratified by Ghana. These include:

- **Convention No. 155** (Occupational Safety and Health [OSH]), which mandates the establishment of policies to prevent occupational accidents and illnesses. This Convention establishes guidelines for comprehensive OSH policies, which could include adaptive measures such as risk assessments, worker training on heat-related illnesses, and safety protocols specifically designed for extreme weather events.

- **Convention No. 161** (Occupational Health Services), emphasizing the provision of occupational health services. This Convention ensures access to occupational health services capable of monitoring and managing health impacts from environmental factors, and would reinforce Ghana's public health adaptation strategies.

- **Convention No. 187** (Promotional Framework for OSH), which encourages the continuous improvement of national OSH systems. This Convention enables continuous improvement of national OSH systems, supporting the ongoing integration of climate adaptation into health and safety standards.

The absence of ratification and alignment with the above ILO OSH Conventions limits Ghana's capacity for comprehensive OSH improvements, particularly in relation to heat-related policies. This gap highlights the need to integrate climate adaptation measures within existing OSH frameworks to protect workers from increasing heat stress. Given Ghana's susceptibility to climate change and the projected rise in heat stress, as demonstrated in the present study, ratifying the above and other ILO Conventions would play a crucial role in managing heat-related risks.

Incorporating the above Conventions into Ghana's OSH policies would also strengthen national resilience by promoting regular workplace risk assessments and updating safety protocols to address rising heat levels. Such measures would help Ghana prepare for projected increases in heat stress and other climate-related risks, contributing to a safer and more resilient working environment.

Furthermore, ratifying and implementing these OSH Conventions aligns with Ghana's broader climate and development objectives. Integrating OSH standards into climate adaptation efforts supports Ghana's commitment to the Paris Agreement by fostering a just transition for workers, enhancing the country's resilience to climate impacts, and reinforcing both worker protections and economic stability.

[63] https://normlex.ilo.org/dyn/nrmlx_en/f?p=1000:11200:0::NO:11200:P11200_COUNTRY_ID:103231

6.2. Policy recommendations for climate adaptation

In a Consultation Meeting carried out as part of the development of this study, local stakeholders identified a set of priority actions to strengthen Ghana's response to workplace heat stress, with particular emphasis on coordination, enforcement, and inclusive adaptation. First, participants underscored the need to strengthen multi-sectoral coordination in workplace heat stress interventions, including closer collaboration between labour, environmental, health, and urban authorities. Within this framework, greater emphasis should be placed on nature-based solutions, such as urban greening, shading, and ecosystem-based cooling measures, as cost-effective and sustainable risk-reduction strategies. Second, it was emphasised that effective responses must explicitly address the informal economy. Given the high prevalence of informal employment in Ghana and its elevated exposure to workplace heat stress, policies and interventions should be designed to reach informal workers and enterprises, ensuring access to protection measures, information, and support mechanisms.

Third, participants recommended the adoption of binding legislation mandating the use of the WBGT index as the basis for workplace heat stress regulation. Drawing on international examples from countries such as Qatar, Belgium, Malaysia, and Singapore, legally defined WBGT thresholds could trigger mandatory hydration breaks, rest periods, and work-rest adjustments, thereby strengthening enforceability and compliance.

Fourth, local stakeholders highlighted the importance of enforcing existing labour and environmental legislation more effectively, noting that improved compliance with current laws would already contribute significantly to mitigating workplace heat stress risks. Fifth, promoting individual awareness and responsibility was identified as an important complementary measure. Workers and the general public should be supported to understand personal heat-mitigation strategies, including hydration practices, rest, appropriate clothing, and early recognition of heat-related symptoms.

Sixth, Consultation Meeting participants emphasised that the findings of the present study should be actively leveraged as a sensitisation and awareness-raising tool for policymakers, employers, workers, and the wider public, translating evidence into accessible messages and practical guidance. Seventh, the Environmental Protection Authority was encouraged to intensify public education efforts through its social media platforms, using targeted campaigns to raise awareness of heat risks, preventive behaviours, and environmental drivers of workplace heat stress. Eighth, stakeholders recommended engaging the National Commission for Civic Education and the Information Services Department to expand civic awareness campaigns, ensuring consistent messaging and broad public outreach on workplace heat stress, climate change, and labour protection. Ninth, the need for further research was highlighted, particularly to identify and promote indigenous and locally adapted solutions to workplace heat stress that reflect Ghana's climatic, cultural, and socio-economic contexts.

Finally, participants stressed that workplace heat stress interventions should be clearly categorised into short-, medium-, and long-term measures to support prioritisation and implementation. Key areas identified across these time horizons include strengthening social dialogue, expanding green spaces, scaling up tree-planting initiatives, and advancing coordinated research and policy development. In this context, the Environmental Protection Authority, the Meltwater Entrepreneurial School of Technology, and the Ministry of Labour, Jobs and Employment were identified as key institutions to lead national research, innovation, and policy development on workplace heat stress mitigation.

In parallel with the above priority actions, to enhance Ghana's climate resilience and protect worker health, the country could consider further aligning its climate adaptation policies with ILO OSH standards. Adopting these standards would establish a comprehensive framework for addressing heat stress and other climate-related occupational hazards, particularly in sectors most vulnerable to heat, such as agriculture, construction, and services. This alignment with ILO OSH standards includes:

1. **Development of National Heat-Stress Guidelines:** Ghana is encouraged to work towards establishing national heat stress guidelines that align with recent ILO recommendations[1] on the prevention and mitigation of heat stress in the workplace, as well as those in Convention No. 155 (Occupational Safety and Health), which mandates workplace policies to prevent accidents and illnesses, and Convention No. 161 (Occupational Health Services), emphasizing the provision of adequate health services for workers. These guidelines should adopt the general OSH protection framework for heat stress recommended by

the ILO[1] that includes, as a minimum standard, the following 10 basic protection requirements (grouped based on ILO's hierarchy of controls; also illustrated in Infographic 4):

- **Risk Assessment:**

1. Participatory risk assessment in the working environment integrating excessive heat.
2. Use of the WBGT as a potential heat stress indicator to assess the level of heat exposure, with varying safety thresholds based on work intensity.

- **Engineering Controls:**

3. Provision of cool, shaded, and ventilated rest areas.

- **Administrative Controls:**

4. Identification of and targeted strategies for worker groups at high risk.
5. Hydration strategies, including adequate sanitation facilities, especially for female workers.
6. Rest, breaks or modified work schedules to limit or avoid exposure to excessive heat, including the ability to self-pace.
7. Heat acclimatization measures for workers without recent heat exposure.
8. Education and awareness on heat stress and heat-related illnesses.
9. Regular medical check-ups and health monitoring.

- **Personal Protective Equipment:**

10. Personal protective equipment designed to protect workers from heat stress.

2. **Implementation of Regular Monitoring and Risk Assessments:** Ghana is encouraged to implement systematic mechanisms for collecting, analysing, and reporting data on workplace heat stress impacts on health and productivity and should aim to increase awareness and communication among employers and workers regarding climate-related occupational hazards, together with consistent enforcement of existing legislation. Moreover, continuous monitoring and risk assessment protocols should be incorporated in workplaces, guided by Convention No. 187 (Promotional Framework for OSH). This would involve employers conducting regular assessments of workplace conditions using, preferably, the WBGT index, to evaluate heat stress levels and assess the effectiveness of heat mitigation measures. Additionally, employers should be encouraged to provide regular updates on worker exposure, health risks, and preventive measures, ensuring transparency and accountability in managing workplace heat hazards.[1]

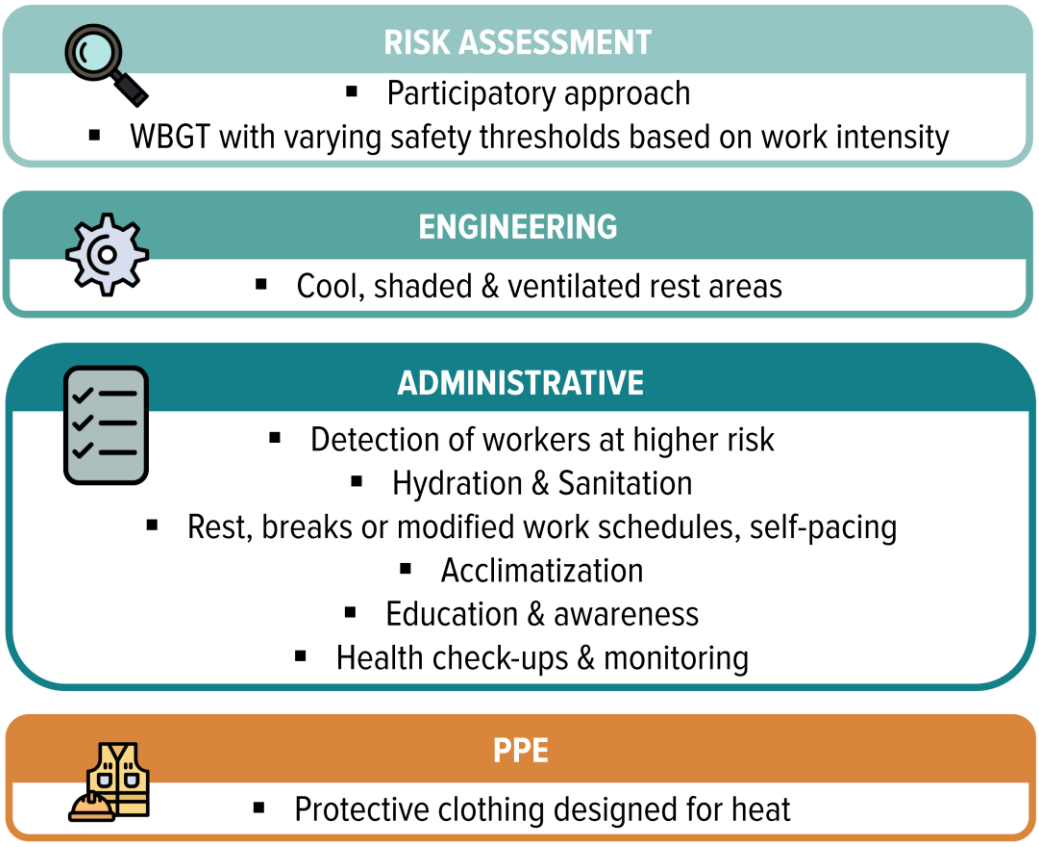
3. **Role of Employers in Minimizing Heat-Related Hazards:** Employers should be encouraged to implement preventive measures for minimizing heat exposure risks. This should include, at a minimum, the development of a nation-wide early warning system, modified work hours during extreme heat, access to cooling solutions, and training for both employers and workers on identifying and responding to heat-related illnesses. Aligning with ILO's Decent Work Agenda, these measures would enhance working conditions and uphold workers' rights to a safe and healthy workplace, particularly critical in Ghana's agriculture and construction sectors, where exposure to high heat exposure is frequent. Particular attention could be given to ensure that the developed frameworks and procedures cover informal workers and micro, small, and medium-sized enterprises, building on existing good practices. Investments in public infrastructure (e.g., shaded rest areas, potable water points, and adequate sanitation near worksites) should be prioritised, as well as the design and use of differentiated personal protective equipment suited to varying heat and humidity conditions.

4. **Integration of Heat Stress into National OSH Policies:** Ghana is encouraged to explicitly incorporate heat stress as a key occupational hazard in its OSH policies, following ILO guidance on climate-responsive OSH frameworks. Policies should include minimum heat safety standards, mandatory reporting of heat-related incidents, and guidelines for high-risk sectors. Additionally, adopting national standards on emergency preparedness for extreme weather events would support worker protection in times of intense heat, aligning with ILO recommendations on OSH practices in a changing climate.[1]

5. **Promotion of Workplace Health Services and Support Systems:** Ensuring that all workplaces provide occupational health services that can monitor, advise, and treat workers affected by heat exposure is essential for worker safety. As per ILO Convention No. 161, access to these services should be mandatory in Ghana, particularly in sectors most vulnerable to heat stress. It is important that Ghana's health services include regular check-ups for workers, first aid for heat-related incidents, and preventive health programs focused on adapting to high-temperature work environments.[1] Expanding social protection measures for heat-affected workers, particularly those in informal and seasonal employment, should be emphasised, together with gender-responsive interventions, supported by targeted research, to better understand and address differentiated impacts. National awareness campaigns can improve understanding of workplace heat stress risks and adaptation measures. Strengthening social dialogue through active involvement of employers' and workers' organisations in the design, implementation, and monitoring of heat adaptation policies is also important.

6. **Utilization of social security funds to incentivise OSH and workplace heat stress adaptation:** Social security funds can be leveraged as an active policy instrument to incentivise OSH compliance and workplace heat stress adaptation. One potential approach is to introduce temporary reductions or suspensions of employer contribution rates, conditional on the verified implementation of workplace adaptation measures, such as cooling infrastructure, modified working hours, improved ventilation, or the provision of appropriate protective equipment. Foregone contributions could be recovered gradually over time, once adaptations are in place and operational. Such mechanisms can support employer cash flow in the short term, enabling necessary investments in workplace heat stress prevention and broader OSH improvements, while contributing to a reduction in work-related injuries and heat-related illnesses over time. In the medium to long term, this can generate savings for social security systems through lower benefit claims, reduced absenteeism, and improved labour productivity. By acting as preventative investors, social security funds can help shift OSH policy from a reactive to a preventive model. Temporarily lowering employer contributions in exchange for demonstrable risk-reducing measures creates financial incentives for enterprises to invest in safer and more resilient workplaces. These early-on incentives can significantly reduce future liabilities for social security administrations by lowering the incidence of occupational injuries, diseases, and disability claims. Overall, this approach aligns employer incentives with long-term system sustainability. Employers benefit from improved liquidity to upgrade workplaces, workers benefit from safer and healthier working conditions with reduced workplace heat stress risk, and social security systems benefit from improved financial sustainability through a healthier and more productive workforce.

Infographic 4. Decent work protection package for workplace heat stress, based on ILO's 10 basic protection requirements (grouped based on the hierarchy of controls).



By adopting the above ILO-aligned policy recommendations, Ghana can strengthen its climate adaptation efforts, create safer working conditions, and foster resilience among its workforce against climate change and rising heat stress. Moreover, implementing these recommendations will contribute to a sustainable, just transition in Ghana's labour market, in alignment with global labour and climate goals.

6.3. Key recommendations for climate adaptation per sector

Rising heat stress is already undermining worker health, productivity, and overall economic resilience in Ghana. In light of the evidence presented in the present study, it is imperative to adopt sector-specific adaptation strategies that not only protect workers but also support continued economic activity. The following recommendations outline targeted measures for each key economic sector, integrating the sector-specific vulnerabilities highlighted in earlier parts of the present study with practical, evidence-based adaptation strategies, ensuring that policy-makers and stakeholders have clear guidance on protecting workers and supporting economic stability in the face of rising workplace heat stress due to climate change. Importantly, these recommendations should be applied in addition to – not in place of – the general OSH protection framework for heat stress recommended by the ILO[1] which is described in Section 6.2. Collectively, the recommendations included in the present study provide a framework for tailoring climate adaptation measures to the unique challenges and opportunities within each economic sector. By implementing these strategies, Ghana can protect its workforce, sustain productivity, and enhance the resilience of its economy in the face of a warming climate.

Agriculture/Fisheries: In agriculture and fisheries, where the majority of work is performed outdoors and workers are directly exposed to the natural elements, adaptation strategies should focus on minimizing heat exposure. These include adjusting work schedules to avoid the hottest parts of the day is essential, alongside implementing on-site measures such as the installation of shade structures, provision of adequate hydration,

and cooling stations. Additionally, adapting crop management practices by shifting planting cycles and choosing heat-tolerant crop varieties can reduce the vulnerability of agricultural production to extreme heat. Worker training on recognizing the signs of heat stress and on implementing first-aid measures further enhances resilience in this critical sector.

Construction: Construction work is characterized by intense physical labour and significant exposure to outdoor heat. To protect construction workers, employers should consider rescheduling work to cooler periods, such as early mornings or late afternoons, and enforcing regular, scheduled breaks during the day. The deployment of portable shading, misting systems, and on-site hydration stations is critical to reducing workplace heat stress. Engineering controls, such as using reflective materials or temporary shade/insulation, can further mitigate the thermal load on construction sites. In addition, worker acclimatization programs and ongoing risk assessments are vital to ensure that adaptation measures remain effective as environmental conditions evolve.

Manufacturing: Manufacturing facilities, whether operating indoors or in partially exposed environments, must address both process-generated and environmental heat. Enhancing indoor climate control through improved ventilation and energy-efficient air conditioning systems is a key priority. Implementing structured work-rest cycles and staggered shifts can help manage cumulative heat exposure. In addition, installing real-time monitoring systems to track WBGT levels enables a proactive response to emerging heat stress risks. Employee education and training on the importance of hydration and heat stress symptom recognition can further support a healthier and more productive workforce.

Mining and Quarrying: For mining and quarrying operations, which often occur in environments with high ambient temperatures or in confined underground spaces, robust environmental controls are crucial. Recommended actions include upgrading ventilation and cooling systems to maintain safer working conditions, as well as scheduling operations to reduce exposure during peak heat periods. Establishing mandatory rest breaks with access to cooled rest areas can help mitigate the physiological strain experienced by workers. Regular monitoring of WBGT, paired with comprehensive risk assessments, will ensure that protective measures are effectively tailored to fluctuating conditions. Where feasible, increased mechanization may reduce the need for direct human exposure to hazardous thermal conditions.

Services: Although the services sector is predominantly indoor, many subsectors (including retail, hospitality, and tourism) are vulnerable to heat stress, especially in facilities with inadequate climate control or in areas where outdoor work is required. Ensuring that workplaces are fitted with efficient cooling and ventilation systems, and that indoor temperatures remain within safe limits during heatwaves will safeguard workers' health and their productivity levels. Flexible scheduling and remote work options can also help mitigate risks for workers, particularly those performing heat-vulnerable jobs/tasks. In addition, service providers are encouraged to develop contingency plans and to conduct regular training and awareness campaigns about the risks of workplace heat stress. Such measures not only protect worker health but also support uninterrupted service delivery during periods of extreme heat.

Transportation and Trade: The transportation and trade sector, which encompasses both outdoor activities and logistics operations, faces unique challenges from heat stress. It is recommended that work schedules be modified to avoid extreme heat, with the establishment of climate-controlled rest areas and loading docks. Equipping drivers and logistics personnel with cooling equipment and appropriate personal protective gear will protect their health, reduce absenteeism, and safeguard uninterrupted service delivery. Moreover, infrastructural improvements, such as installing shading and misting systems at key transport hubs, can reduce heat exposure and maintain the efficiency of supply chains. These measures are critical to ensuring that the sector's operational continuity is not compromised by rising heat levels.

6.4. Role of the ILO's decent work agenda

Implementing the above-mentioned ILO-aligned policy recommendations and advancing the broader goals of the ILO Decent Work Agenda will generate important benefits for Ghana, as demonstrated in this study. This agenda aims to provide safe, productive, and fair working conditions, which are increasingly critical as Ghana faces heightened climate impacts, particularly rising heat stress levels. By adopting these measures, Ghana will strengthen its climate adaptation efforts, enhance workplace safety, and build resilience among its workforce against climate change and increasing heat stress. Furthermore, as shown below, adopting these measures will support a sustainable and just transition within Ghana's labour market, aligning with both global labour standards and climate objectives.

- **Promoting Safe and Healthy Workplaces in Ghana Amidst Rising Heat:** The Decent Work Agenda[64] prioritizes safe and healthy workplaces as essential for sustainable and equitable employment. For Ghana, adopting OSH Conventions such as Convention No. 155 (Occupational Safety and Health) and Convention No. 161 (Occupational Health Services) establishes a solid framework for safeguarding workers in sectors particularly susceptible to extreme heat, including agriculture and construction. As highlighted in the present study, these sectors are crucial to Ghana's economy but are highly vulnerable to climate impacts, making the implementation of heat stress protections a pressing need. Establishing national heat stress guidelines and mandatory mitigation strategies aligns closely with the Decent Work Agenda's commitment to securing safe conditions across industries.[64]

- **Enhancing Productivity through Climate-Responsive OSH Measures:** Safe working conditions are essential to sustaining worker productivity, a core priority of the Decent Work Agenda.[64] Implementing heat adaptation strategies, such as structured work-rest cycles and hydration protocols, allows Ghana to minimize productivity losses due to heat stress.[1] These measures help maintain productivity levels during periods of intense heat, reducing economic disruptions and supporting a resilient labour market.[1] The Agenda's focus on fair and productive workplaces highlights the importance of addressing environmental risks that could jeopardize economic stability and workforce productivity.[64]

- **Focusing on Vulnerable and Informal Workers:** Informal workers, particularly those in agriculture, construction, and other high-risk sectors, are especially vulnerable to climate impacts due to limited access to social protections and occupational safety measures.[1] The Decent Work Agenda promotes inclusive and fair working conditions, ensuring protections for vulnerable groups.[64] Applying OSH standards to address climate risks helps prevent these workers from being disproportionately affected by rising heat. By mandating workplace safety measures, Ghana can enhance both climate resilience and social equity, fostering safer work environments across all segments of its labour market.

- **Advancing Social Protection and Fair Conditions:** The Decent Work Agenda emphasizes social protection as a cornerstone of fair and sustainable employment.[64] By adopting ILO OSH Conventions, Ghana can establish climate-responsive social protections, including health monitoring, emergency response services, and compensation for heat-related illnesses. This approach promotes equitable conditions amid climate challenges, aligning with the Agenda's commitment to secure and just employment for workers facing environmental stressors.[64]

- **Contributing to Ghana's Just Transition to a Climate-Resilient Economy:** Incorporating the Decent Work Agenda into climate adaptation initiatives also aligns with Convention No. 187 (Promotional Framework for OSH), which encourages continuous improvement in national OSH policies. This framework is key to Ghana's just transition, supporting the development of a climate-resilient economy

[64] International Labour Organization. Decent work and the 2030 Agenda for sustainable development. Geneva, Switzerland (https://www.ilo.org/topics-and-sectors/decent-work-and-2030-agenda-sustainable-development).

by fostering equitable and sustainable working conditions across all sectors. By embedding OSH standards within climate policies, Ghana can protect its workforce, ensuring that workers—especially those in high-risk sectors—are supported against the impacts of climate change and increasing heat stress.

In summary, designing future climate and environment policies in line with the ILO Guidelines for a just transition towards environmentally sustainable economies and societies for all will generate important public health, societal, and labour market benefits for Ghana. This will ensure that that these policies maximize the opportunities and minimize any challenges from the transition to a climate-resilient economy, including for workers in heat sensitive sectors. Coordinated efforts between the Government of Ghana, international organizations, and civil society are essential to ensuring that climate actions promote economic recovery and safeguard employment. Aligning climate adaptation strategies with the ILO Decent Work Agenda provides Ghana with a comprehensive approach to addressing climate impacts on labour, helping ensure that its workforce remains safe, productive, and resilient in the face of rising heat.

7. Scenario analysis to decent work and SDG implementation

Building on the findings described in Sections 2-5, scenario analyses were used to examine what changes if Ghana fully implements the ILO Decent Work Agenda and advances the 2030 Agenda. The analysis follows the ILO results logic used in Decent Work Country Programmes, moving from inputs to activities, to outputs, to outcomes, and to impact (Infographic 5). It also uses the GDP and employment projections reported in Section 5 for 2040 and 2060 under SSP1-2.6 (low emissions) and SSP5-8.5 (high emissions), contrasting the two policy futures (SSP1-2.6 vs. SSP5-8.5) and highlighting the "policy dividend" of decisive action. The approach is grounded in the four pillars of decent work: employment, rights at work, social protection, and social dialogue. These pillars are the core of the ILO mandate and guide national action and international support.

Infographic 5. Decent Work theory of change for heat-safe work in Ghana: from inputs to impact.



Inputs include strong political commitment to the four Decent Work pillars, ratification and enforcement of key ILO Conventions, budgetary allocations for heat-risk management, as well as access to climate and social finance. They also include reliable data on workplace heat exposure and labour conditions, as well as tripartite dialogue that brings government, employers, and workers to the same table. Finally, they include ILO's technical support under the Global Flagship Programme on Building Social Protection Floors and the Guidelines for a just transition towards environmentally sustainable economies and societies for all.

Activities translate the inputs into practice. They comprise: (1) ratification and enforcement of ILO Conventions 155, 161 and 187; (2) adoption of a national heat-stress legislation anchored in the 10 ILO protection requirements and the recommendations of Section 6; (3) extending social-protection floors to cover heat-related sickness, income protection and injury benefits for formal and informal workers; (4) shift of public- and private-sector investment equal to 0.3-0.5% of GDP per year toward heat-safe, energy-efficient workplaces and public spaces (efficient cooling, urban heat-island mitigation, shaded transport hubs), and skills for green and heat-safe jobs; and (5) strengthening labour inspection and tripartite social dialogue to co-design sector-specific protocols; and (6) establishing monitoring systems to track WBGT, lost work time, and heat-related illness.

Outputs follow quickly. More worksites apply heat-safe procedures. More workers have access to shade, water, rest, as well as first aid and health checkups. A larger share of workers is covered by health services and income support when heat disrupts work. Labour inspection has practical tools for oversight. Local governments and firms use heat alert systems. Trade unions and employer groups have agreed playbooks for peak-heat days.

These outputs align with the ILO Just Transition Guidelines, which call for policy coherence, social dialogue, rights, and decent work in climate action.

Outcomes include fewer hours lost to heat and absenteeism, lower injury and illness rates, higher retention, and steadier productivity. Women, youth, and informal workers gain from safer jobs and better income protection. Firms report fewer heat-related disruptions and smoother logistics. Municipal services and public works run more reliably during hot months.

The long-term ***impact*** is a larger effective labour supply, safeguarded GDP, fewer jobs lost to heat, and higher output. Progress is visible on SDG 8 on decent work and economic growth, SDG 3 on health and well-being, and SDG 13 on climate action. This path also supports SDG 1 on poverty reduction through income security when work must pause.

Scenario design

The scenarios examined use the projections in Section 5 of the present study for 2040 and 2060, coupling global climate pathways with domestic policy efforts. The numbers below are those in Section 5, representing the heat penalty against the 1985 to 2014 baseline. Key results are summarized in Infographics 6-7.

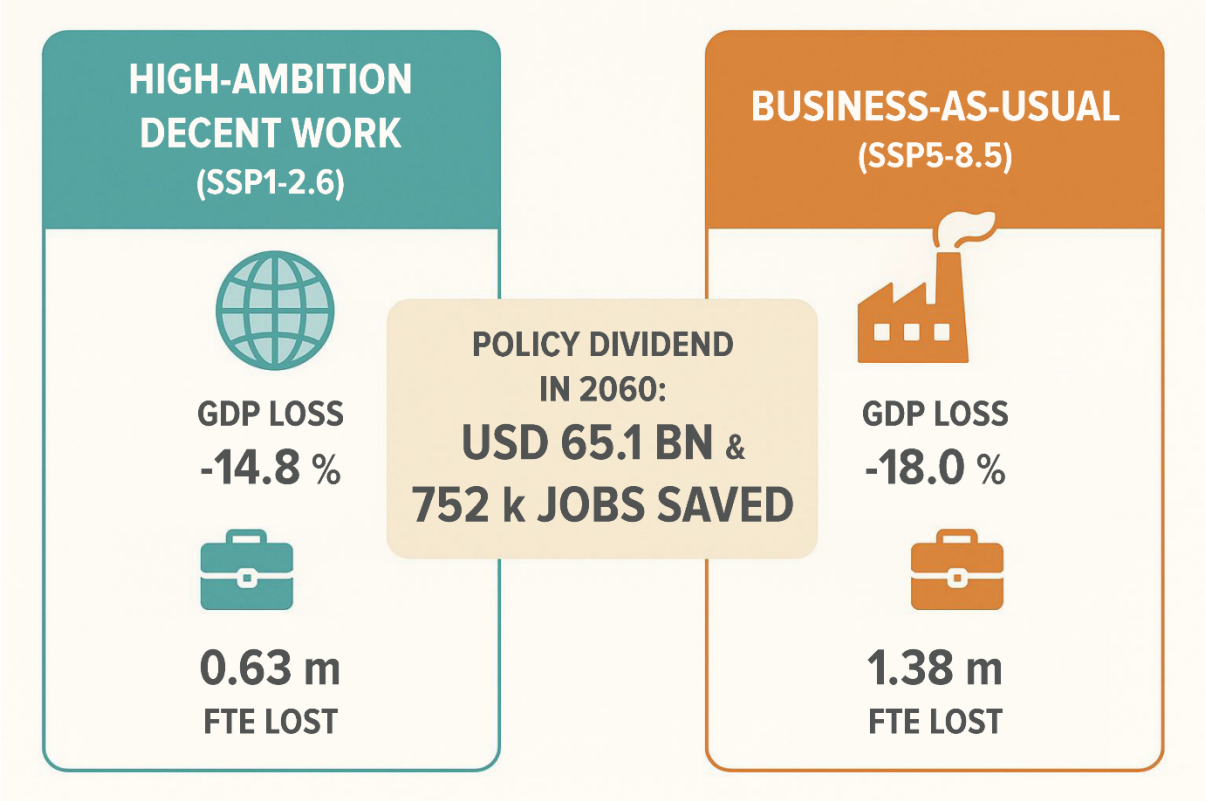
- **Scenario A: High-Ambition Decent Work (Decent Work + SDGs implemented; climate consistent with SSP1-2.6).** Ghana implements the Decent Work pillars at scale. By 2040 the GDP loss from heat is about **23.2 billion USD**, or 13.1%. By 2060 it reaches about **100.2 billion USD**, or 14.8%. Annually, the labour market loses about **550,000 FTE jobs** in 2040 and about **632,000** in 2060 due to lost productivity from heat stress. Agriculture carries the largest absolute losses, followed by services, construction, and manufacturing. With Decent Work measures in place, a larger share of companies can keep work going safely during peak heat. The benefit is seen in fewer lost hours and fewer medical events. The social protection floor limits income shocks for low-income workers when work must pause. The combined effect is to keep outcomes near the lower end of the projection band under any emissions path.

- **Scenario B: Business-as-Usual (fragmented uptake; climate consistent with SSP5-8.5).** Policy progress is partial and uneven. By 2040 the GDP loss is about **31.1 billion USD**, or 14.6%. By 2060 it is about **165.2 billion USD**, or 18%. Annually, the labour market loses about **796,000 FTE jobs** in 2040 and about **1.38 million** in 2060. The burden remains largest in agriculture and services. Heat events cause more stoppages and more illness. Informal workers, women in service jobs, and outdoor workers in agriculture and construction bear the heaviest costs. Social protection coverage remains thin, so income shocks deepen poverty when work halts.

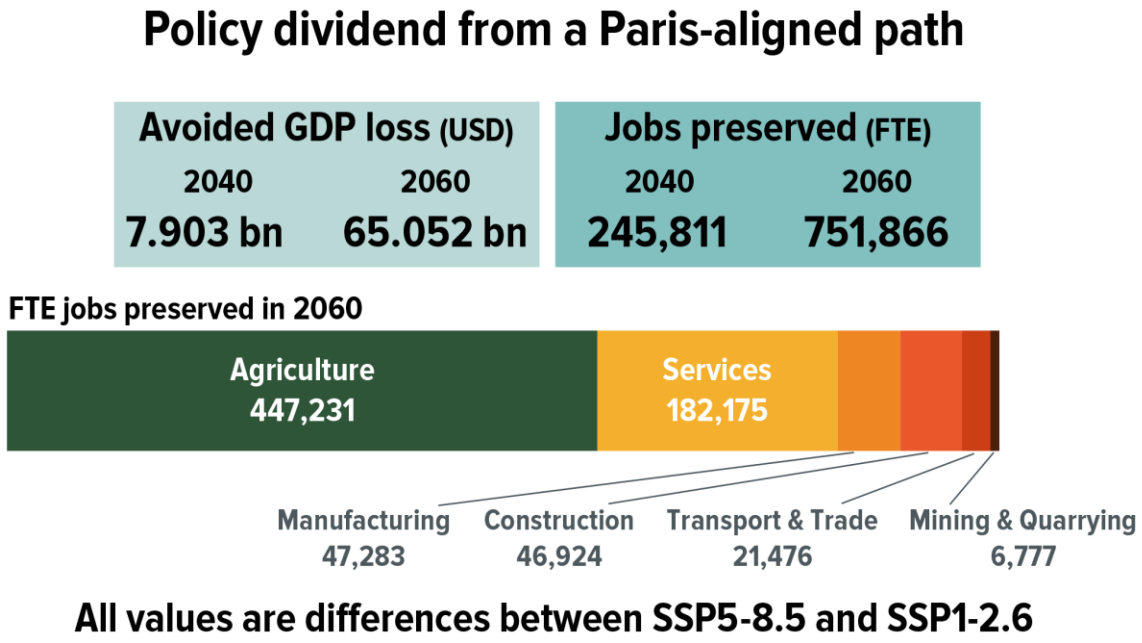
The policy dividend

The choice of path carries a large dividend. The gap between the high-ambition path and SSP5-8.5 in 2060 is about **65 billion USD of annual GDP**. In job terms the gap is about **752,000 FTE jobs** saved each year (Infographic 7). If the world follows SSP3-7.0 rather than a Paris-aligned path, the gap rises to about 1.4 million jobs. Much of the avoided loss sits in agriculture and services because of their weight in output and employment. These gains accumulate over time through better worker retention, fewer stoppages, and more resilient local supply chains.

Infographic 6. Scenario analysis to decent work and sustainable development goal implementation in Ghana in relation to workplace heat stress. Figures calculated as differences between SSP5-8.5 and SSP1-2.6 based on the results presented in Section 5.



Infographic 7. GDP and labour market benefits of implementing the decent work and sustainable development goals in Ghana, particularly in relation to workplace heat stress. Figures calculated as differences between SSP5-8.5 and SSP1-2.6 based on the results presented in Section 5.

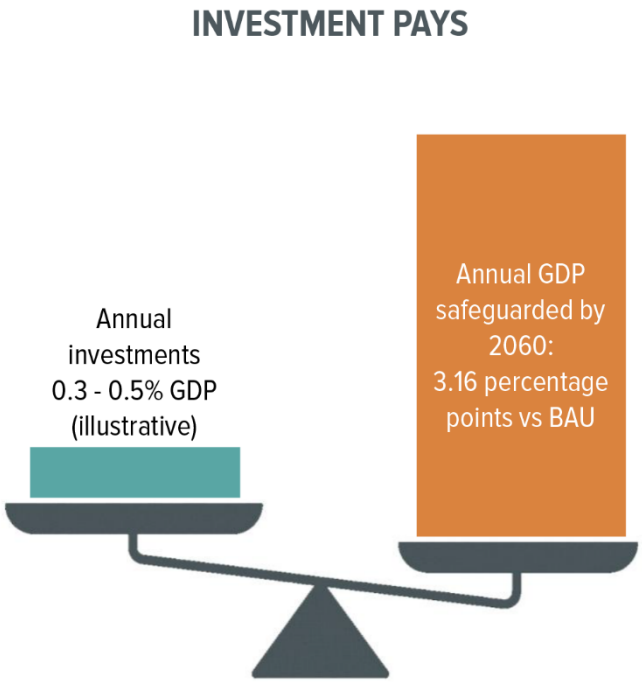


Qualitative pathways and distributional results

Employment levels remain higher when heat-safe schedules and efficient cooling are in place. Earlier starts and longer midday breaks protect output in agriculture and construction. Indoor climate control and ventilation reduce errors and slowdowns in retail, hospitality, and light manufacturing. Absenteeism falls when hydration and medical monitoring are standard practice. Occupational health services linked to social protection detect early signs of illness and avoid severe cases. These changes are consistent with ILO guidance on safe and healthy work and with the aim of social protection floors to secure access to health care and basic income security.

Equity improves when the floor reaches informal workers and when minimum heat safety rules cover outdoor and street-based work. Cash support during heat alerts prevents income collapse, food insecurity, and child labour risk. Targeted measures for pregnant workers, young workers, and older workers reduce health risks. Social dialogue helps balance rest breaks and pay rules so that safety does not mean a wage penalty.

Infographic 8. Investment case: cost vs returns of heat safe workplaces (calculated as difference between SSP5-8.5 and SSP1-2.6 based on the results presented in Section 5).



Implementation priorities

Implementing the high-ambition path requires a series of steps. First, adopt and enforce a **national heat protection standard across sectors, triggered by WBGT-based thresholds**. Use public procurement to require compliance on public works and service contracts. Second, extend the **social protection floor** so that heat-related sickness and income loss are covered for both formal and informal workers. Third, **finance efficient cooling**, shade, ventilation, and water access for small companies and public facilities and invest in urban heat mitigation and climate-smart agriculture. As shown in Infographic 8, even small annual investments directed toward implementing policies consistent with a Paris-aligned pathway (SSP1-2.6) will generate significant returns by 2060. **All steps should be designed and monitored** through tripartite dialogue in line with the Just Transition Guidelines. They set out the need for policy coherence, rights, and dialogue so that climate action delivers decent work.

The evidence in the present study shows that Ghana already faces a heavy heat penalty. The size of future losses depends on global mitigation but also on domestic execution of the Decent Work Agenda. A full package centred on safe work, social protection, green investment, and dialogue can preserve output and protect jobs as temperatures rise. This is how Ghana can turn climate risk into a path for safer work and sustained growth while advancing the SDGs.

Next steps: A suggested timeline to implement the recommendations stemming from this study is presented in Infographic 9. Initial proposed actions as a follow-up to this study may include the need to strengthen national capacity on the use of the WBGT index and related thresholds, in support of the adoption of WBGT-based OSH legislation. Heat-related occupational health modules should be integrated into Ghana's Third Nationally Determined Contribution implementation. Moreover, a National Technical Workshop could be convened to bring together local stakeholders to translate the agreed recommendations into a concrete, time-bound action plan addressing the impacts of rising temperatures on worker health and welfare, business operations and

productivity, the national economy, and community resilience. The workshop should also focus on raising awareness of workplace heat stress risks among workers, micro-, small-, and medium-enterprises, as well as communities. It should also aim to build policymaker capacity to design and implement measures addressing the impacts of rising temperatures on labour productivity and business resilience, as well as providing practical training and support for workers and employers on preventive and adaptive responses to workplace heat stress.

Infographic 9. Implementation timeline: a path to achieve heat-safe workplaces.



8. Research limitations

While providing valuable insights, the analysis described in the present study is subject to technical limitations stemming from its methodology, data sources, and assumptions, which should be acknowledged in the context of Ghana's specific conditions.

One important limitation lies in the **modelling assumptions** used to estimate heat-induced work losses. The study applies a recently developed global labour loss function that links WBGT to the fraction of a work shift lost to heat exposure.[59] This function was derived from field studies across various countries and is calibrated for an "average, experienced, acclimatized worker" operating under typical conditions.[59] While this provides a robust general framework, it may not capture all nuances of Ghanaian labour contexts. For instance, actual work-rest behaviours, acclimatization levels, and protective measures in Ghana could differ from the study's general assumptions. Moreover, the historical baseline chosen for analysis (1985-2014) is already approximately 0.75 °C warmer than pre-industrial times.[45] This means the projected climate-induced impacts in workplace heat stress are **conservative**, as some climate warming that has already occurred before the baseline is essentially "included into" the reference scenario. In effect, using a late-20th-century baseline avoids biases due to outdated work patterns but **underestimates the absolute impact of climate change** on heat stress by not accounting for pre-1985 warming. Policymakers should recognize that real-world impacts could be larger if referenced to true pre-industrial conditions.

Another set of limitations arises from the **data sources and resolution** used in the analysis. Owing to sparse localized data, the study relies on global datasets and model outputs that have been downscaled or resampled for Ghana. Climate variables (temperature, humidity, etc.) were taken from a single global climate model and downscaled to a grid of about 5 km, then aggregated for analysis (see Annex 1). Other key datasets (population, economic output, etc.) were available at coarser resolutions (~25 km) and likewise had to be interpolated or merged. While these steps ensure consistency across data layers, they inevitably **smooth over local variability**. Ghana's complex terrain and microclimates – from cooler higher altitude areas to hotter, humid coastal cities – may not be fully captured by grid-averaged climate data. Small geographic "hotspots" (for example, inner-city districts with urban heat island effects or particular valleys with extreme conditions) could, therefore, be under-represented. Similarly, using national or gridded averages for labour and economic activity can mask differences in heat exposure within sectors or regions. The model distributes impacts based on generalized population and sector data rather than detailed local employment patterns, so the **spatial distribution of losses** should be viewed as indicative rather than exact. Furthermore, there are **coverage gaps in labour data**, especially regarding informal employment. Official statistics and economic output data likely undercount informal and unregistered workers, who represent a significant proportion of Ghana's workforce. These workers are often in heat-exposed sectors such as agriculture, construction, or street trade, yet their productivity losses may not fully translate into the formal GDP metrics adopted in the present study. As a result, the projections may **underestimate total work hours lost and economic costs**, since any heat-stress impact on the sizable informal sector is not rigorously captured by formal data. In essence, data limitations mean that the findings paint a broad picture rather than a granular one, and actual on-the-ground impacts could diverge in specific locales or sub-populations.

The **climate projection scenarios** used in the present study also introduce technical caveats. The analysis focuses on four SSP scenarios (SSP1-2.6, SSP2-4.5, SSP3-7.0, and SSP5-8.5) to represent a range of future greenhouse-gas emission pathways. These SSPs are global storylines and serve as useful proxies for low, moderate, and high warming futures, but they are not tailor-made for Ghana. In reality, Ghana's future emissions and development path may not neatly correspond to any single SSP. Ghana's outcomes could fall between scenarios or follow a different trajectory. Moreover, by necessity only a subset of possible scenarios was analyzed. Intermediate pathways (for example, scenarios reflecting uneven development or delayed mitigation beyond those chosen) were not explicitly modeled, meaning that the **full uncertainty range** of climate outcomes is not captured. A related limitation is that the study's climate projections are based on a **single climate model** (UKESM1-0-LL) for temperature and humidity. While this model was high-resolution and is a state-of-the-art choice, relying on one model's output means that the results do not reflect inter-model variability. Different climate models can project somewhat different patterns of warming, humidity, or extreme heat days for Ghana. By using one model, the analysis assumes its simulation is representative, but if that model

underestimates (or overestimates) future heat extremes in Ghana, the projected work productivity losses would be skewed accordingly. In addition, the climate data were handled at a monthly time scale. This captures long-term warming trends well, but may not fully account for **short-term heatwaves or day-to-day extremes** that can sharply impact work capacity. Any sub-monthly variability and the potential for consecutive extremely hot days (which can compound stress on workers) are largely averaged out in the scenario data. Therefore, while the SSP-based projections give a credible envelope of future conditions, one should bear in mind that **scenario and model choices** introduce uncertainty. The actual climate impact on Ghana could be somewhat higher or lower than depicted, especially if unmodeled extremes or divergent regional climate changes occur.

There is also **uncertainty in the workability and productivity response functions** when applied to Ghanaian conditions. The physiological model underpinning the work-hour loss estimates is grounded in empirical studies, but these studies have inherent variability and may not include all the circumstances present in Ghana's labour force. For example, the response function assumes a given relationship between WBGT and the need for rest, based on an average worker sample. In practice, Ghanaian workers' ability to cope with heat can vary with factors such as age, health status, type of work, and cultural practices (e.g. timing of work shifts or rest periods). The analysis does not explicitly differentiate how a young, healthy construction worker might tolerate heat versus an older agricultural worker or a street vendor with limited shade. This one-size-fits-all function means that **individual and subgroup differences** are not captured, as some workers may experience greater productivity loss than predicted, while others less. Moreover, the model presumes **current levels of acclimatization and work routines remain constant in the future**. It does not account for potential adaptation measures by workers or employers in response to rising heat (such as shifting work hours to cooler times of day, improving hydration and rest breaks, or mechanization to reduce physical strain). If such adaptations become common, they could mitigate some productivity losses, meaning the projected impacts might overstate what actually occurs. On the other hand, if extreme heat increases beyond physiological coping ranges, the simplistic linear response may understate losses for the hardest-hit days. While the present study reports uncertainty ranges (e.g. confidence intervals) around the estimated losses, these primarily reflect the statistical uncertainty in the empirical function and climate variability, rather than the full spectrum of **behavioural and physiological uncertainty**. In summary, users of the present study's results should recognize that the translation from heat levels to lost work hours is based on an idealized average response. Real-world outcomes could deviate if Ghanaian workers' responses to heat stress differ from the model's assumptions.

Finally, the **estimation of WBGT and sectoral heat exposure** in this analysis involved necessary generalizations that limit precision. The WBGT for each location and sector was computed from meteorological data using a standard method (Liljegren's approach) with set parameter assumptions. For instance, **indoor working conditions** are modeled by assuming no direct solar radiation and a modest, fixed air movement of 1 m/s (to mimic light ventilation or fans). Indoor temperature and humidity were estimated as a function of outdoor conditions without accounting for building-specific cooling or insulation. In reality, indoor environments in Ghana vary widely. Some offices or facilities are air-conditioned (keeping WBGT lower than outdoor), while in other workplaces without cooling, heat can build up more than the model's simple ratio may predict (especially during power outages or in poorly ventilated spaces). Likewise, **underground or enclosed worksites** (e.g. any mining or tunnel operations) were approximated from surface weather data, which may not fully reflect actual thermal conditions underground where geothermal heat and ventilation play a role. The exposure assumptions also treat entire sectors uniformly in terms of work setting. For example, the agriculture and construction sectors were considered mostly outdoors (hence directly exposed to ambient heat), whereas sectors such as services or manufacturing were treated as predominantly indoor. In a Ghanaian context, this generalized approach may be an oversimplification. Within services, a tourism worker guiding tours outside faces different heat stress than a bank employee inside an air-conditioned branch, yet both are counted under "services." Even within outdoor sectors, micro-environmental differences (working in shade versus sun, use of protective clothing, etc.) are not distinguished. Consequently, the **sector-level results should be interpreted as averages**, as actual heat exposure and productivity loss can vary within a sector based on specific job roles and locales. Moreover, because the analysis aligns workers with grid-cell climate data (using population distributions and national economic data), any mismatch between where people live versus where they work could introduce minor errors. For example, if many workers commute from cooler highlands to hotter coastal workplaces, the model may underestimate their exposure by tying them to home location climate. These granular issues are inherent in a

nationwide modeling study and highlight that the findings are **indicative trends subject to these aggregation effects**.

In conclusion, while the present study's projections of climate-induced workplace heat stress impacts on jobs and productivity in Ghana are grounded in the best available science and data, they remain constrained by the above technical factors. The use of global models and datasets, necessary assumptions about worker behaviour and sectoral exposure, and scenario uncertainties all mean the results are **approximate and conditional**. These limitations do not undermine the overall message that workplace heat stress poses a serious and growing challenge to Ghana's labour productivity, but they do delineate the **bounds of confidence** for the numbers presented. Policymakers and stakeholders should thus view the quantitative estimates as **guidelines within an expected range** and complement them with local observations and knowledge. A transparent understanding of these technical caveats will ensure that decisions and strategies informed by the present study properly account for its scope and the uncertainties in projecting climate change impacts on Ghana's workforce. This nuanced interpretation will help ground policy responses in realism, neither underestimating the threat of workplace heat stress nor overextending the precision of modelled forecasts.

Annex 1 – methodology

A1.1. Calculation of WBGT

For the calculation of the WBGT, the approach of Liljegren[65] was adopted because it is considered the most accurate method when calculating WBGT from meteorological data.[66] The environmental temperature, relative humidity, and wind speed data required for the calculation of WBGT were obtained from the relevant historical and SSP datasets provided in Section A1.2. Wind speed was corrected for height above the ground using previous methodology.[67] Solar radiation was estimated[68] for the midday of the middle day of each month using the geolocation (longitude and latitude) of each grid cell, while correcting for cloud coverage using published literature.[69] For indoor conditions, solar radiation was considered negligible, while wind speed was kept constant at 1 m/s, as this velocity is more indicative of the occupational settings where some air movement is generated by workers while they walk or move in the worksite.[66] Indoor temperature and humidity were estimated as a function of outdoor conditions.[70] Similarly, for the mining industry, underground temperature[71] and humidity[72] were estimated as a function of surface conditions.

A1.2. Datasets and Methodology

The present analysis included a collection of global datasets from recognized sources outlined in the following sub-Sections, including historical and projected data on population counts, global terrain elevation, climate, emissions, economic activity and demographics. Each dataset adopted different resolution and format, requiring resampling. Climate data were resampled to a target resolution of 3 arc minutes (0.05 degrees, 7200 longitude x 3600 latitude), while other datasets were resampled to 15 arc minutes (0.25 degrees, 1440 longitude x 720 latitude) using Python-based tools. This ensured consistent alignment across datasets for accurate merging and analysis.

A1.2.1. Population Datasets

Historical population data from the GPWv4 dataset,[73] covering the years 1990, 1995, 2000, and 2005, was obtained at a 15 arc-minute resolution. This dataset was already aligned with the target resolution and contained important information related to grid cells, including country mapping and land-water areas and it was used as the reference dataset for subsequent analysis.

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Population projections datasets, based on the SSP1, SSP2, SSP3, SSP4, and SSP5 were obtained from standard sources.[74,75] These projections were originally available at a resolution of 7.5 arc minutes (0.125 degrees 2880 longitude and 1440 latitude) and required resampling to 15 arc minutes. The process was performed using the rasterio library, applying the "Resampling.sum" method to aggregate population data across the new grid cells.[76] After resampling, datasets for rural, urban, and total populations were merged for the years 2010 to 2100, in 10-year increments.

A1.2.2. Global Terrain Dataset

The global terrain data from the GEBCO terrain model[77] was used. The data was initially provided at a resolution of 15 arc seconds (86400 longitude and 43200 latitude), and it was averaged into 15 arc-minute grid cells. During this process, negative values representing undersea topography were excluded, focusing only on land elevations for merging with climate data.

A1.2.3. Climate Datasets

The CMIP6 climate historical and projection datasets, derived from the "UKESM1-0-LL" model under the "r1i1p1f2" experiment,[78] were downloaded using the CHELSA (Climatologies at High Resolution for the Earth's Land Surface Areas) Python library. This library provides downscaled climate data estimates at a horizontal resolution of 30 arc seconds.[79,80,81] To ensure compatibility and facilitate computational efficiency, the datasets were upscaled to a target resolution of 3 arc minutes (0.05 degrees, 7200 x 3600 grid). Monthly data from the "UKESM1-0-LL" model was gathered for the following experiments: Historical, SSP1-2.6, SSP2-4.5, SSP3-7.0, and SSP5-8.5. The historical dataset spans 1985 to 2014, while the projection data covers 2020 to 2100. Specifically, near surface air temperature and near surface relative humidity, wind speed, maximum temperature, and total cloud cover percentage were obtained.

A1.2.4. Demographic Dataset

Hybrid gridded demographic dataset was obtained at resolution of 290 latitude by 720 longitude.[82] This demographic dataset contains fractional percentages for various age ranges, spanning from 5 to 65 years old. The data includes both historical and projected population distributions, covering the period from 1950 to 2050.

A1.2.5. Land Cover Dataset

The 2022 C3S Land Cover dataset (v2.1.1)[83] at 300-meter resolution was downloaded via the CDSAPI library, using lccs_class values to identify urban areas (class 190). A binary mask was created, assigning 1 to urban areas and 0 to others, and added to the dataset. The data was then resampled to a 15 arc-minute resolution by summing

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[83] Copernicus Climate Change Service (C3S). (2019). Land cover classification gridded maps from 1992 to present derived from satellite observation, in Climate Data Store (CDS).

the urban area cells using xarray's coarsen method.[84] A final dataset was produced with country-level details via geographical mapping, calculating each country's percentage of urban area grid-by-grid.

A1.2.6. Greenhouse Gas Emissions Datasets

Greenhouse gas emissions data were downloaded from the EDGAR datasets[85] and divided across four sectors:

- Agriculture sector, which included emissions from agricultural soils and enteric fermentation.
- Mining and Quarrying sector, which included methane emissions from natural gas extraction and processing.
- Manufacturing sector, which included emissions from chemical processes, industrial combustion, iron and steel production, solvent use, oil refining, and waste incineration.
- Transport and trade sector, which included emissions from aviation (landing and takeoff), road transportation, railways, pipelines, and off-road transport.

Each sector's emissions were aligned by latitude and longitude, summed, and resampled to a 15 arc-minute resolution. The emissions were then merged into a single dataset, indexed with sectoral and country-level details via geographical mapping. Finally, a new dataset was created to quantify each country's percentage contribution to emissions within each sector, calculated grid-by-grid.

A1.2.7. GDP Dataset

Country-level economic data on the structure of value added was obtained from the United Nations Statistics Division (Latest Data Upload: January 2025) for the period 1970-2023.[86] The dataset contains the contributions of various sectors, including agriculture, hunting, forestry, fishing (ISIC A-B), mining, manufacturing, utilities (ISIC C-E), manufacturing (ISIC D), construction (ISIC F), wholesale, retail trade, restaurants and hotels (ISIC G-H), transport, storage and communication (ISIC I), other activities (ISIC J-P), as well as total value added, to each country's GDP, expressed in constant 2015 USD.

In addition, a multi-country, multi-sector, multi-scenario gridded dataset of projected gross domestic product (GDP) was developed for the years 2040 and 2060. Historical sectoral GDP for each country was sourced from UN National Accounts,[87] and these values were spatially distributed to grid cells based on the emissions dataset. Future total GDP projections for each grid cell, scenario (SSP1–SSP5), and years (2040, 2060) were obtained from the Zenodo global gridded GDP dataset v7.[88]

For each country, the proportional contribution of each sector per grid cell was computed based on the distribution for the year 2023. These sectoral shares were then applied to projected total grid cell GDPs for 2040 and 2060 to estimate sector-specific GDP at each location under each scenario.

Future grid-cell and sector-level GDP values were initially expressed in purchasing power parity (PPP) international dollars. To enable cross-country comparison and economic analysis in nominal terms, the PPP-based GDP values were converted to market exchange rate (MER) GDP using country- and year-specific Price Level Ratios (PLR). The PLR for each country and scenario was extrapolated to 2040 and 2060 using a linear fit to World Bank historical PLR values (2000-2019).[89] The conversion was performed as follows: GDP_MER=GDP_PPP*PLR

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[84] Hoyer S., Hamman J., xarray: 1. Arias P, Bellouin N, Coppola E, et al. Technical Summary. In: Masson-Delmotte V, Zhai P, Pirani A, et al, eds. Climate Change 2021: The Physical Science Basis Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press; 2021. labeled arrays and datasets in {Python}. Journal of Open Research Software, 2017. 5(1).

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[86] United Nations Statistics Division, Department of Economic and Social Affairs, Statistics Division - National Accounts (Latest Data Upload: January 2025). Value Added by Economic Activity, at constant 2015 prices - US Dollars.

[87] https://unstats.un.org/unsd/snaama/Basic.

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[89] https://data.worldbank.org/indicator/PA.NUS.PPPC.RF.

A1.2.8. Employment Dataset

Economic activity data was obtained from ILOSTAT,[90] providing employment data across different economic sectors and genders. The 14 variables provided in the ILO dataset were divided into six sectors using the standard intermediate-level aggregation[91] as follows:

- Agriculture (ISIC rev.4: A).
- Mining and Quarrying (ISIC rev.4: B).
- Manufacturing (ISIC rev.4: C).
- Construction (ISIC rev.4: F).
- Transportation and Trade (ISIC rev.4: H, G).
- Services, which included all remaining activities: utilities (ISIC rev.4: D, E), accommodation and food service activities (ISIC rev.4: I), information and communication activities (ISIC rev.4: J), financial and insurance activities (ISIC rev.4: K), real estate; business and administrative activities (ISIC rev.4: L, M, N), public administration and defense (ISIC rev.4: O), education (ISIC rev.4: P), human health and social work activities (ISIC rev.4: Q), and other services (ISIC rev.4: R, S, T, U).

A1.2.9. Sector Distribution

Two datasets were used to calculate the distribution of each sector on each grid cell: the urban area land cover data (providing the percentage of urban area per grid cell; see A1.2.5) and the emissions data (including sectoral emission percentages; see A1.2.6). For the Agriculture, Mining-Quarrying, Manufacturing, and Transportation-Trade sectors, sectoral emission percentages were used from the above-mentioned emissions dataset as the distribution parameter within the grid cells, while urban area percentages were applied for the Construction and Services sectors.

In cases where the emissions dataset did not include information for mining in the country of interest, the Global Mines and Minerals dataset from the United States Geological Survey was utilized.[92] The original data consisted of point locations specified by latitude and longitude coordinates for various mining sites. To align with the target resolution of 15 arc minutes, the point data was transformed into grid cells. During this process, an equal distribution method was applied within each grid cell containing mining points.

Next, using the ILO employment dataset (with gender-specific employment counts), the number of male and female workers in each sector was calculated for each grid cell based on sectoral employment data and the percentage contribution from emissions or urban area. This process was repeated for all six economic activity sectors, with the final dataset containing estimated number of male and female workers per sector, indexed by latitude, longitude, sector, and country.

Similarly, for each grid cell, using the above-mentioned GDP dataset, the GDP by sector of economic activity was calculated based on the percentage contribution from emissions or urban area. This process was also repeated for all six sectors, producing a final dataset containing the estimated GDP in USD millions, indexed by latitude, longitude, sector, and country.

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[90] International Labour Organization (ILO). Employment by sex and economic activity -- ILO modelled estimates, Nov. 2023 (thousands) -- Annual, in ILO Modelled Estimates (ILOEST) Database. 2023, ILO, Geneva, Switzerland.
[91] United Nations Statistics Division, Department of Economic and Social Affairs (2008). International Standard Industrial Classification of All Economic Activities (ISIC) - Statistical papers, Series M No. 4/Rev.4. New York, USA.
[92] United States Geological Survey. Global Mines and Minerals dataset: https://mrdata.usgs.gov/mineral-operations. Accessed: October 1, 2024.

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