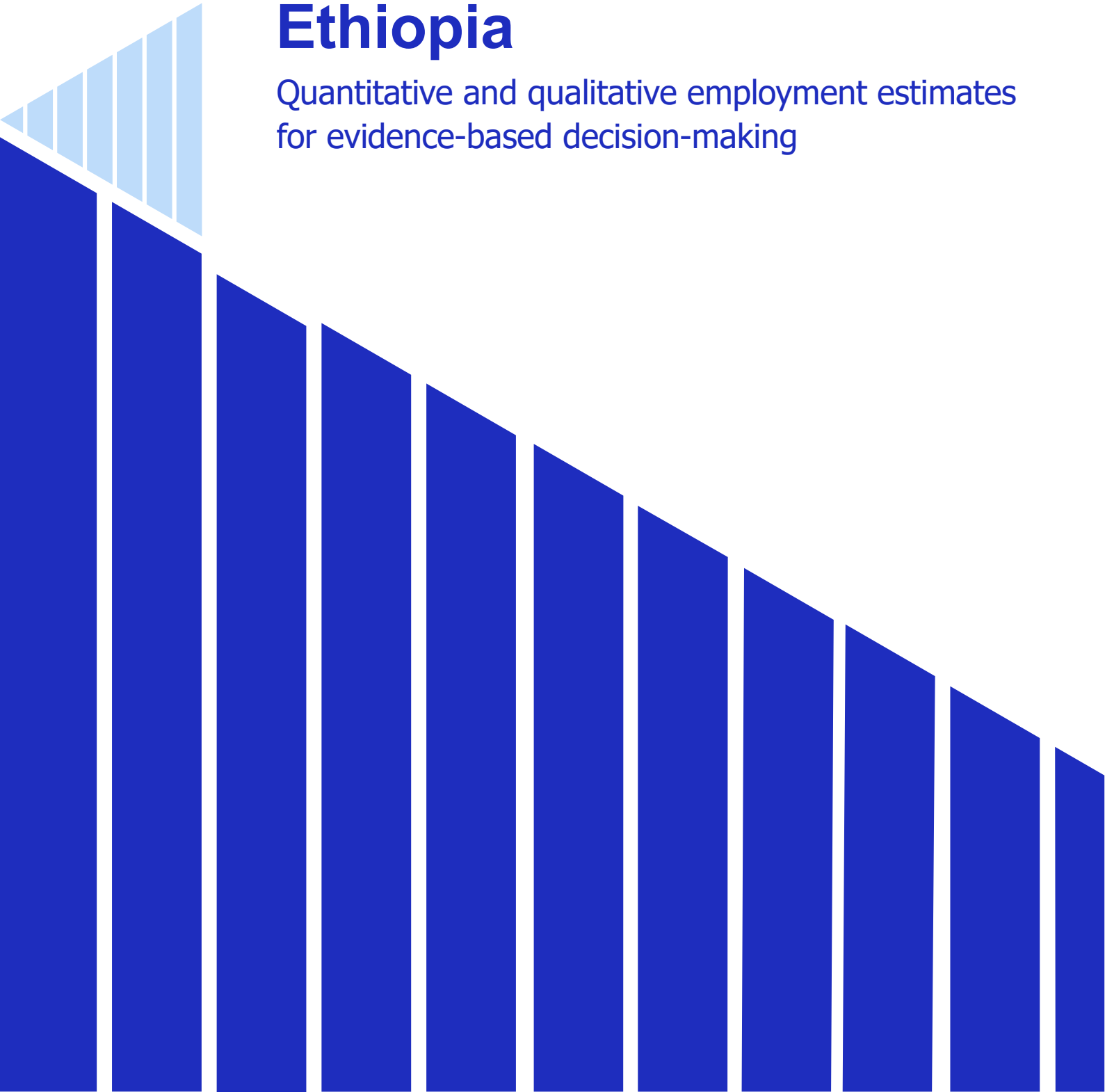
International Labour Organization

Impacts of heat stress on jobs and productivity in Ethiopia

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, this study builds on the available data to provide just transition input to Climate Prosperity Plans (CPPs). It evaluates the implications of heat stress in Ethiopia'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 134 million inhabitants, Ethiopia is the 10th most populous country in the world and the 2nd most populous in Africa.[2,3] The capital and largest city is Addis Ababa in the central part of the country, while other significant cities include Dire Dawa to the east, Mekelle in the north, as well as Adama and Hawassa in the south and south-east.

[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] Worldometer (2024). Ethiopia Population. https://www.worldometers.info/world-population/ethiopia-population. Accessed: 28/11/2024.
[3] Central Intelligence Agency (2025). Ethiopia. The World Factbook (2025 ed.). https://www.cia.gov/the-world-factbook/countries/ethiopia. Accessed: 28/11/2024.

Ethiopia underwent significant political change over the past decade, marked by leadership transition and periods of unrest.[4] In 2018, after years of anti-government protests, Prime Minister Abiy Ahmed came to power promising dramatic reforms and national reconciliation. His administration released political prisoners, welcomed back exiled opposition groups, and forged a historic peace agreement with neighbouring Eritrea – an achievement that earned Abiy the Nobel Peace Prize in 2019.[5]

Despite early reforms, Ethiopia's political opening remained fragile as ethnic and regional tensions persisted. In late 2020, a conflict erupted between the federal government (allied with regional forces) and the Tigray People's Liberation Front in the northern Tigray region.[6] This civil war, which later spread to parts of Amhara and Afar, caused extensive loss of life and infrastructure damage.[6] A peace agreement in November 2022 formally ended the two-year Tigray conflict, allowing humanitarian access and paving the way for reconstruction.[6] However, security challenges endured elsewhere: an insurgency by the Oromo Liberation Army intensified in Oromia, and sporadic ethnic-based violence flared in other regions.[6] National elections were held in mid-2021 with the ruling party winning a large majority, but voting was not conducted in Tigray due to the war.[6] Overall, the combination of reform efforts and conflicts has defined Ethiopia's governance landscape: bold policy shifts toward liberalization on one hand, and on the other, periods of emergency that tested the country's stability and humanitarian capacity.[7]

1.2.2. Economic trends and performance

Ethiopia experienced strong economic performance in the last 20 years but also faced macroeconomic imbalances and shocks. Real GDP growth averaged nearly 10% per year from 2004 up to 2018 – one of the highest rates in the world – driven largely by public infrastructure investments.[4,7] This rapid expansion improved living standards and contributed to poverty reduction. Despite these gains, Ethiopia's per capita income stood at just 790 USD in 2019, reflecting its status as one of the poorest countries globally.[8] Vulnerability remains high, particularly among populations reliant on rain-fed farming and pastoralist systems. Subsistence agriculture, which is prone to recurrent drought and environmental risks, continues to be the dominant livelihood for a significant share of Ethiopians, underscoring the need for policies and investments that bolster resilience and reduce poverty.[8]

After 2018, growth moderated amid internal and external challenges. Following the onset of the COVID-19 pandemic and the northern conflict, GDP growth fell sharply by about 3.8% in 2022.[4] Activity rebounded in 2023 as stability began to improve, with estimates of 6-7% growth in 2022-2023, but this remained below the pre-2018 pace.[4] High inflation emerged as a serious concern: price growth spiked into double digits, reaching over 30% in 2022[8] due to supply disruptions, global commodity shocks, and expansionary policies. Soaring food, fuel, and fertilizer costs eroded household purchasing power and undercut prior gains in poverty reduction.[6]

Persistent trade imbalances and a fixed exchange rate regime led to foreign exchange shortages and rising external debt vulnerabilities. By the early 2020s, Ethiopia's public debt had become a concern, prompting the government to seek relief under the G20 Common Framework for debt treatment.[4,7] Recognizing these challenges, authorities initiated major economic reforms to shift the country's state-led development model towards a more sustainable, private-sector-driven path.[4,7] A Homegrown Economic Reform Agenda launched in 2019 outlined plans to liberalize key sectors and improve competitiveness. Concrete steps were taken in 2020-2021, such as opening the telecom industry to private operators and preparing the banking sector for foreign investment.[4,7] In mid-2024, the government accelerated reforms by floating the exchange rate and easing forex controls, modernizing monetary policy, and phasing out untargeted subsidies. These measures, supported by a new IMF program and World Bank development financing, aim to stabilize the economy and spur broad-based

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[4] World Bank (2024). Ethiopia - Country Climate and Development Report. Washington, D.C. World Bank Group.
[5] Klobucista C. (2020). Ethiopia: East Africa's Emerging Giant. Council on Foreign Relations. https://www.cfr.org/backgrounder/ethiopia-east-africas-emerging-giant. Accessed: 28/11/2024.
[6] Bertelsmann Stiftung (2024). BTI 2024 Country Report — Ethiopia. Gütersloh: Bertelsmann Stiftung. https://bti-project.org/en/reports/country-report/ETH. Accessed: 28/11/2024.
[7] World Bank (2025). The World Bank in Ethiopia. www.worldbank.org/en/country/ethiopia/overview. Accessed: 28/11/2024.
[8] ILO (2024). Ethiopia - Situation and Priorities. International Labour Organization. Geneva, Switzerland. https://www.social-protection.org/gimi/ShowCountryProfile.action?iso=ET. Accessed: 4/12/2024.

growth.[4,7] Going forward, Ethiopia's economic management is focused on controlling inflation, resolving debt distress, and translating macroeconomic gains into tangible benefits such as jobs and income for its young and growing population.[4,7]

1.2.3. Social development and challenges

Ethiopia made social progress in 2015-2018, but recent crises have strained livelihoods and public services. Robust growth contributed to a decline in poverty rates, and the national poverty headcount fell from 39% in 2004 to about 24% in 2016.[4,7] There were notable improvements in access to basic services: for example, millions gained access to clean water and electricity, and childhood vaccination rates doubled, contributing to better health outcomes. By 2019, Ethiopia's human development indicators, while still low, were on an upward trend. However, overlapping shocks since 2018 (drought, conflict, and COVID-19) have reversed some gains.[4,7,9] Household incomes and consumption have declined, and living standards deteriorated for the first time in decades. An estimated 20 million people were internally displaced or otherwise affected by the recent conflict in the north, and the economic fallout from the war and pandemic pushed many households back into poverty.[4,7,9]

Employment and livelihoods remain heavily tied to agriculture and vulnerable to weather fluctuations. Nearly two-thirds of Ethiopia's workforce is engaged in agriculture, often in subsistence farming and pastoralism.[4,8,10] This sector's dominance means that droughts or floods directly impact incomes, food security, and rural jobs.[4,7] Every year about 2 million young Ethiopians reach working age, putting pressure on the labour market to create sufficient jobs. Urban areas have seen growth in services and manufacturing employment, yet underemployment is widespread, and formal jobs are scarce for youth.[9] The government has expanded social protection programs to cushion vulnerable groups. The flagship Productive Safety Net Program provides cash or food transfers to over 8 million food-insecure rural residents, and a community-based health insurance scheme now covers roughly 32 million people.[8] Despite these efforts, overall safety net coverage is low: only about 7.4% of the population receives any social protection benefit, below the Sub-Saharan Africa average of 17%.[8] Basic public services in Ethiopia also face quality and funding gaps, reflected in a Human Capital Index of just 0.38 during 2020,[4,7] one of the lowest levels globally.

In sum, while the 2014-2019 period saw improvements in poverty reduction and social outcomes, the later years have been marked by heightened food insecurity, displacement, and stress on health and education systems. Addressing these social needs and rebuilding human capital are central to Ethiopia's recovery agenda.

1.2.4. Climate-related vulnerabilities and adaptation

Climate variability and change are increasingly undermining Ethiopia's economic and social stability, as the last decade brought a series of climate-related shocks. The country is highly vulnerable to droughts. The 2020-2022 drought episode was the worst in 40 years and devastated livelihoods across southern and eastern Ethiopia.[4,7,9] Millions of pastoralists in lowland areas lost livestock and saw water sources dry up, while farmers in rain-fed agricultural zones suffered consecutive poor harvests. At the peak of this crisis, more than 20 million Ethiopians faced severe acute food insecurity, requiring emergency aid to survive.[4,7,9] Even as drought gripped one part of the country, other regions experienced flooding that washed away crops, damaged infrastructure, and displaced communities.[4,7,9] This combination of extreme drought and flash floods – often in the same year – aligns with scientific evidence and warnings that climate change will increase weather volatility. A desert locust infestation in 2019-2020, fueled by unusual rainfall patterns, further compounded food shortages by ravaging crops and pasture.[4,7,9]

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[9] Boyer C.J., Bayntun C., Iglesias M., Woyessa A., Dorey S.G., Rabie T.S. (2024). Ethiopia - Climate and Health Vulnerability Assessment. Washington, D.C.: World Bank Group. http://documents.worldbank.org/curated/en/099070324141519567. Accessed: 4/12/2024.

[10] Trading Economics (2025). Ethiopia - Employment In Agriculture (% Of Total Employment). https://tradingeconomics.com/ethiopia/employment-in-agriculture-percent-of-total-employment-wb-data.html. Accessed: 4/2/2025.

Rising temperatures and unpredictable rains pose a long-term threat to Ethiopia's predominantly agrarian economy.[11] Climate projections indicate that, without adaptation, annual economic losses will mount: average GDP losses due to climate shocks are estimated at 1-1.5% of GDP currently and could reach 5% of GDP by the 2040s.[4,11] These impacts hit the poorest and most vulnerable communities hardest, potentially pushing millions more into poverty through lost output and livelihoods.[4,7,9] Labour productivity and agricultural yields (especially livestock) are expected to suffer as heat stress intensifies and precipitation becomes more unstable.[4,11] Pastoral lowland regions are particularly at risk, given their exposure to drought and limited coping mechanisms.[4,11] Climate change is, thus, not only an environmental concern but a socio-economic challenge: it threatens to slow Ethiopia's structural transformation and job creation, and it exacerbates food insecurity and malnutrition in already vulnerable populations.[4,9,11] In 2023, after five consecutive failed rainy seasons, around 15-16 million people needed emergency food assistance despite an improved main harvest.[12]

The government, with support from international partners, is integrating climate resilience into its development strategies. Ethiopia has a 10-Year Development Plan that emphasizes building a Green, Climate-Resilient Economy, and it released a comprehensive Country Climate and Development Report in 2024.[4] Priorities include expanding drought-resistant irrigation, strengthening early warning systems via the national meteorological agency, and scaling up social safety nets to protect those most affected by climate shocks.[4] Efforts such as large-scale reforestation (the Green Legacy initiative planted billions of trees) and investments in climate-smart agriculture are underway to restore landscapes and improve food security.[4,7,9]

While climate change presents formidable risks, there are also opportunities. For instance, with the right reforms, Ethiopia's agricultural sector could potentially adapt and even increase output under warmer, wetter conditions.[4,11] Overall, the past decade has underscored that building resilience to climate impacts is critical for Ethiopia's future growth and for safeguarding the welfare of its people in the face of increasingly frequent droughts and floods.

[11] Dove C.M. (2022). Ethiopia – Climate Risk Country Profile. Washington, D.C.: World Bank Group. http://documents.worldbank.org/curated/en/099432006152216345. Accessed: 4/12/2024.
[12] Food and Agriculture Organization (2024). Country Briefs: Ethiopia. https://www.fao.org/giews/countrybrief/country.jsp?code=ETH. Accessed: 4/12/2024.

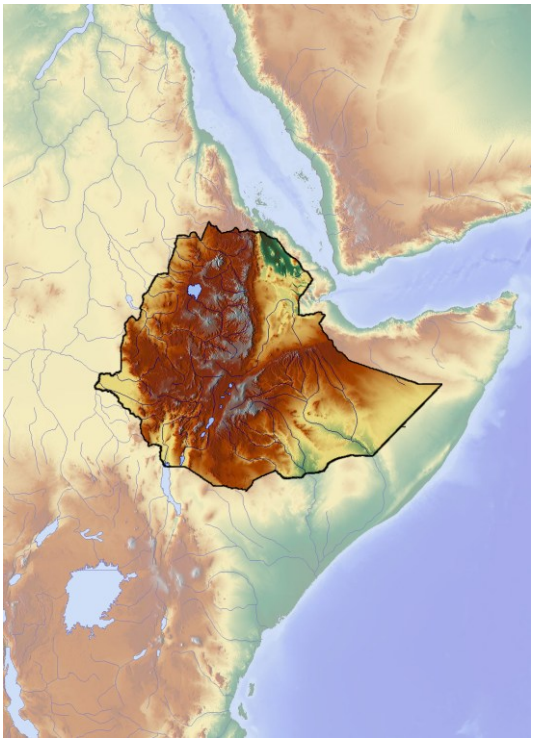
2. Current and future heat exposure and climate change

2.1. Current weather and climate overview

Ethiopia is a landlocked country in Northeast Africa, spanning roughly 1.1 million km^2 (Figure 1). It shares borders with Eritrea to the north, Djibouti and Somalia to the east, Sudan and South Sudan to the west, and Kenya to the south. The country's diverse geography encompasses equatorial rainforests with high rainfall and humidity in the south and southwest, Afro-Alpine zones on the peaks of the Simien and Bale Mountains, and arid lowlands in the northeast, east, and southeast.[11,13] These marked variations in topography and climate underpin Ethiopia's unique ecosystems, agricultural practices, and resource distribution.

Ethiopia's climate is highly diverse due to its varied topography, encompassing everything from humid tropical regions to arid deserts. In general, much of the country is dry sub-tropical, but rainfall and temperature vary widely by elevation and location.[11,14] High-altitude areas experience cool temperatures (sometimes near freezing at night), whereas lowland areas are much hotter, with extreme peaks reaching 45-50°C. Nationwide, the mean annual temperature is 22.6°C, with monthly averages ranging from ~21.5°C in December to ~25°C in April.[11,14]

Figure 1. Ethiopia physical map.[14]



Rainfall in Ethiopia is strongly seasonal and unevenly distributed. The primary Kiremt monsoon (mid-June to mid-September) delivers 50–80% of the annual rainfall in most regions.[11] A shorter rainy season (Belg, February-May) provides additional precipitation in parts of central and northern Ethiopia, while the rest of the year is generally dry.[11] Nationally, mean annual precipitation is on the order of 816 mm (1991-2020 average).[11] However, there are large spatial variations, with totals ranging from less than 300 mm in the arid north-eastern and south-eastern lowlands to around 2,000 mm in the south-western highlands.[11] The following trends highlight Ethiopia's growing climate variability:

- **Rising Temperatures:** Ethiopia has been warming in recent decades. Average temperatures have risen by about 1°C since 1960 (approximately +0.25 °C per decade).[11] The warming has been most pronounced during the July-September period. Also, the country is experiencing more heat extremes: the frequency of very hot days and nights has increased substantially.[11] For example, the number of "hot nights" (nights in the top 10% of temperature variability) climbed by ~37% between 1960 and 2003, and the frequency of extremely hot days rose by ~20%. These higher temperatures contribute to greater evapotranspiration and reduced soil moisture.[11]
- **Changing Rainfall Patterns:** Long-term rainfall trends are more difficult to discern due to high natural variability. Year-to-year rainfall fluctuates significantly, and Ethiopia historically experiences cycles of wet and dry years. That said, an overall decline in rainfall has been observed in parts of the country over the past 30-40 years. Some areas show a marked decrease in precipitation. For instance, the south-central region has seen roughly 20% less rainfall on average since 1960.[11] Moreover, the timing and reliability of rains have shifted. Notably, the Belg spring rains in central/northern Ethiopia have become

[13] World Bank (2021). Ethiopia Climate Change Overview and Country Summary. Climate Change Knowledge Portal. Washington, D.C.: World Bank Group. https://climateknowledgeportal.worldbank.org/country/ethiopia. Accessed: 4/12/2024.
[14] The map was made using http://www.maps-for-free.com

increasingly stronger and less predictable in recent decades.[11] This increased variability, influenced in part by Indian Ocean temperature patterns, has been linked to more frequent drought episodes.[11] Overall, the combination of rising temperatures and erratic rainfall underscores Ethiopia's growing climate variability.[11]

- **Extreme Weather Events:** Ethiopia is highly prone to climate-related extreme events, especially droughts and floods, which pose recurrent challenges to livelihoods and infrastructure.[11] Historical climate variability, combined with the warming trend, has increased the frequency and severity of the following events:
  - **Droughts:** Recurrent drought is Ethiopia's most destructive climate hazard.[11] Droughts have become more frequent and severe since the 1970s, and major drought episodes have led to humanitarian crises. For example, the 2011 Horn of Africa drought left 4.5 million Ethiopians in need of food assistance, and an even worse drought in 2015 (the country's worst in decades) affected nearly 10 million people.[15] These events devastate agriculture and water resources, exacerbating food insecurity in affected areas.[11]
  - **Floods:** Ethiopia also experiences periodic flooding, including both flash floods and riverine floods triggered by heavy seasonal rains.[11] In recent years, flood occurrences have become more frequent and widespread.[11] Severe floods cause displacement of communities, damage to croplands, and destruction of infrastructure.[11] The combination of intense rainfall events and environmental factors (such as land degradation) has heightened flood risk in various parts of the country.[11]
  - **Heatwaves:** As temperatures rise, extreme heat events are an emerging concern.[11] The observed increase in hot days and nights suggests a growing risk of heatwaves and heat stress periods.[11] While Ethiopia's high elevations moderate temperatures in many populated areas, lowland regions are seeing more episodes of extreme heat.[11] Consistent with broader African trends, the incidence of hot extremes (including heatwaves) has been rising.[16] Elevated heat not only impacts human health but can also reduce crop yields and labour productivity, compounding the challenges during drought periods.[11]

2.2. Choice of environmental indicators

To characterize the prevailing environmental conditions for work in Ethiopia, 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.[17]

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

[15] World Weather Attribution (2015). Ethiopia drought, 2015 – a livelihood crisis. https://www.worldweatherattribution.org/ethiopia-drought-2015. Accessed: 4/12/2024.
[16] 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.
[17] 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.

productivity.[17,18,19,20] 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 experienced by 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.[17,21,22,23] 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.[1,24] 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.[25]
- **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.[26]
- **Fatigue and cognitive impairment:** Higher WBGT levels are associated with quicker onset of fatigue and reduced cognitive function, impacting decision-making and coordination.[1,27,28]
- **Heat-related illnesses:** Prolonged exposure can result in dehydration, heat cramps, heat exhaustion, or even heat stroke, especially in high-intensity work environments.[1,26] Working in a hot environment for a significant part of the year can lead to acute/chronic kidney injury.[1,26]

Choice of time constant: The present 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.

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[18] 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.
[19] 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.
[20] ACGIH, Heat stress, TLVs and BEIs: threshold limit values for chemical substances and physical agents & biological exposure indices, ACGIH, Editor. 2020, ACGIH: Cincinnati.
[21] 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.
[22] 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.
[23] 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.
[24] World Health Organization and World Meteorological Organization (2025). Climate change and workplace heat stress: technical report and guidance. Geneva, Switzerland.
[25] 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.
[26] 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.
[27] Flouris A.D. (2019). Human thermoregulation. in: Périard J., Racinais S., eds. Heat stress in sport and exercise: Springer.
[28] 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.

2.3. Current heat and environmental conditions

Figure 2 illustrates the quarterly average maximum environmental temperatures across Ethiopia. The maps show a clear impact of altitude. The central and north-western highlands remain much cooler than the surrounding lowlands. Most highland areas show averages of 25-30°C, while the Afar and eastern lowlands often exceed 35°C and push toward 39°C. Hot corridors trace the Rift Valley and the low basins in the west and south. An analysis of the maps indicates the following:

Seasonality

- **Q1 (Jan-Mar)** is already hot in many lowlands. The Afar Triangle, the eastern Somali Region, the South Omo lowlands and parts of Benishangul-Gumuz register widespread temperatures above 33-35 °C. The highlands remain markedly cooler.
- **Q2 (Apr-Jun)** is the peak heat season. Heat expands across the east and north-east with very hot conditions in Afar and along the northern Rift. Much of the western and southern lowlands also warm further. The highlands warm but keep a clear thermal contrast with the low country.
- **Q3 (Jul-Sep)** is the coolest quarter for most of the country. The Kiremt rains and cloud cover drop daytime maxima across the highlands into the mid-20s. The lowlands remain hot, and Afar stays extremely hot, but the cool footprint over the plateau is at its largest.
- **Q4 (Oct-Dec)** marks a transition back to warmer conditions. Heat re-emerges along the eastern and southern lowlands, while the highlands stay relatively moderate.

Spatial patterns

A persistent hot ring surrounds the cooler plateau. The most extreme heat is concentrated in Afar and adjacent low basins toward Djibouti and Eritrea. The Somali Region and the south-western and western lowlands are also hot for most of the year. The Addis Ababa–Oromia highlands, Amhara highlands, and areas around Lake Tana are consistently cooler. The Rift Valley cuts a warmer band through central Ethiopia, producing local pockets of higher maxima within otherwise cooler highland zones.

Implications for labour and OSH planning

- **Outdoor and heavy work** in Afar, the eastern lowlands, and the south-western lowlands face the greatest heat risk for most of the year.
- **The highest risk window** is Q2, with Q1 and Q4 also demanding strong protections in high-risk regions. Q3 offers relative relief across the highlands but not in the hottest lowland basins. Heat-sensitive activities should shift to cooler hours and seasons where possible.
- **Urban centres** in lowland settings such as Dire Dawa, Semera, and Gambela require extra attention, while highland cities such as Addis Ababa will generally face lower risk during the day but can still experience warm spells that require site-level management.

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

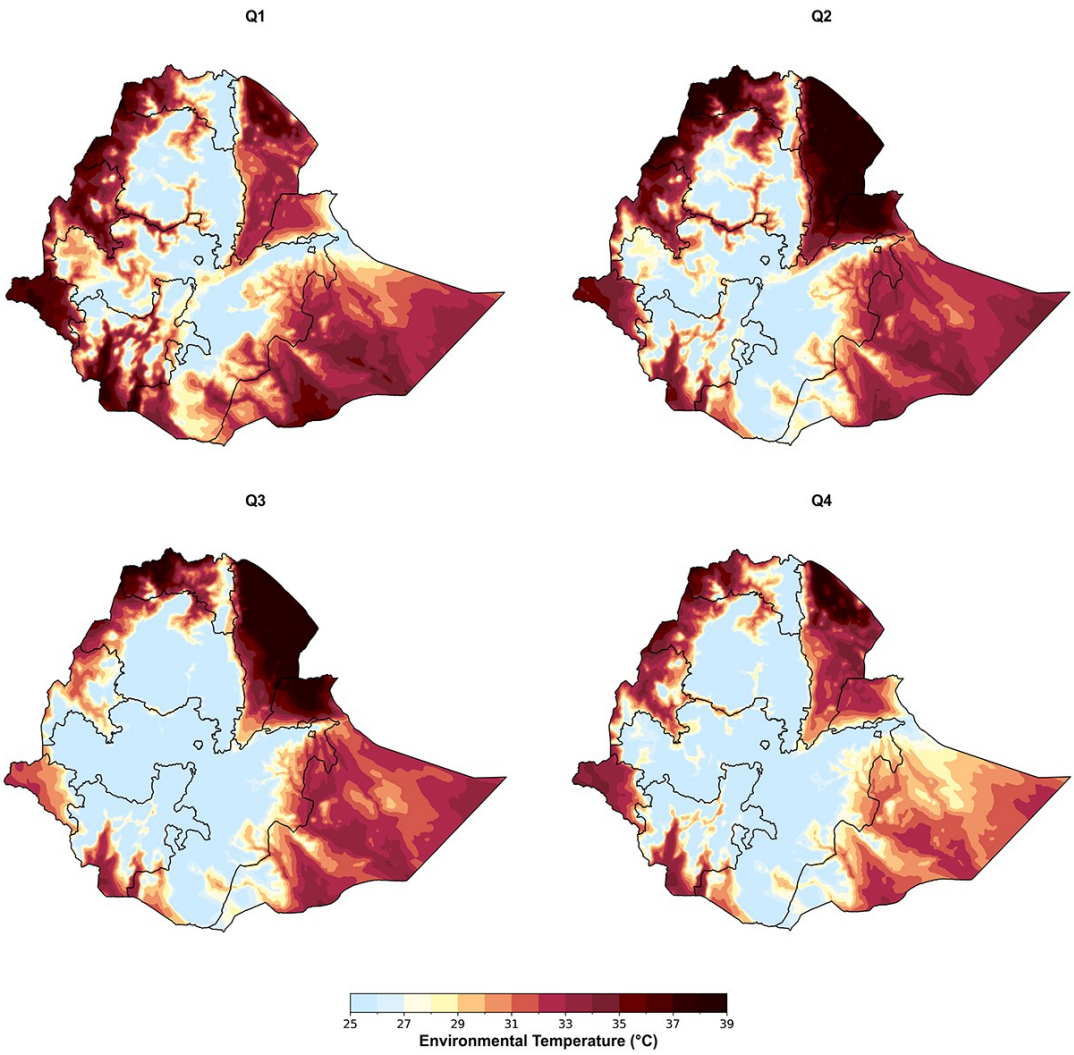


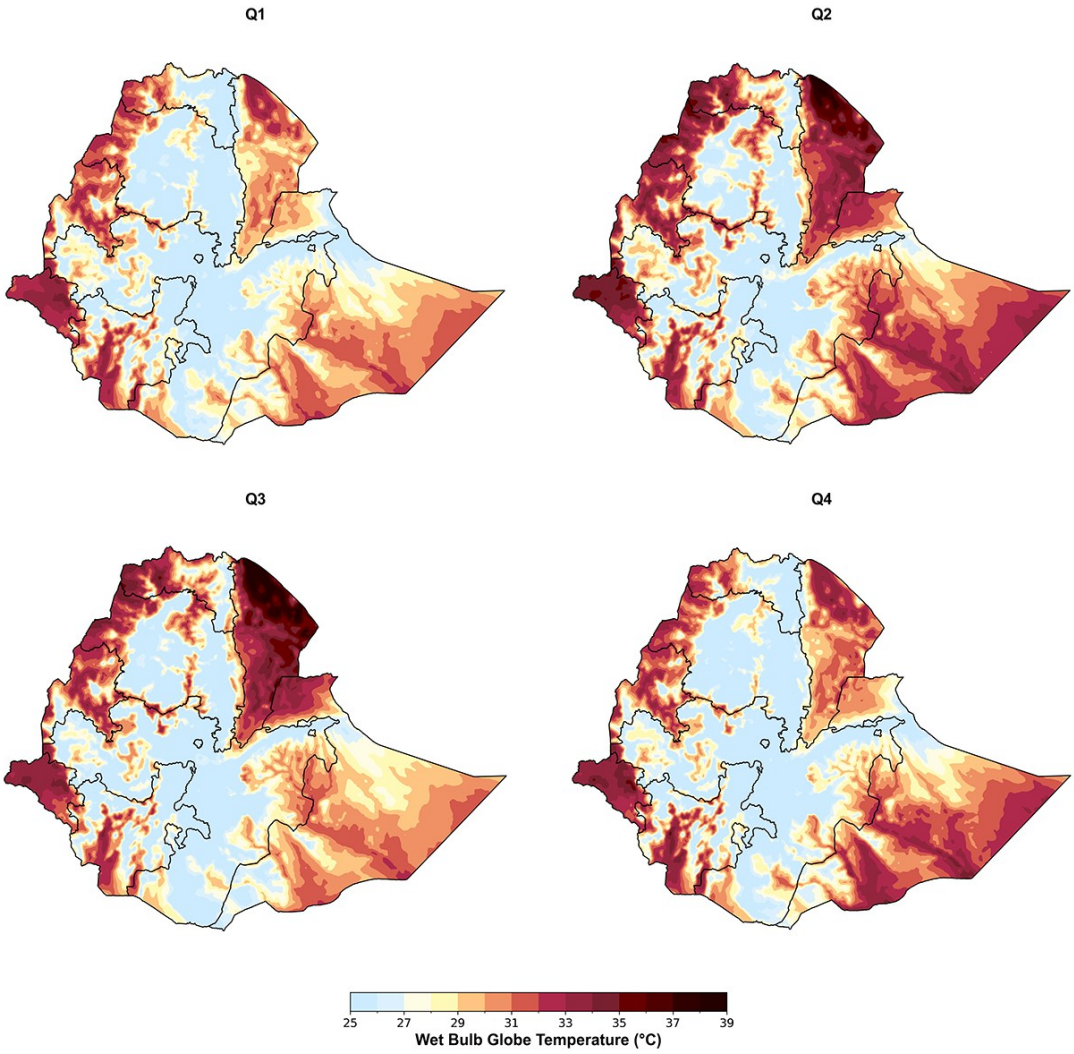
Figure 3 illustrates the quarterly average maximum WBGT across Ethiopia. WBGT is an important measure of heat stress, taking into account not only temperature but also humidity, wind speed, and solar radiation, which makes it particularly useful in assessing the risk of heat stress for working people. A close inspection of the maps provides the following observations:

Seasonality

- **Q1 (Jan-Mar):** Heat stress is already high across most lowlands. WBGT is in the extreme range of 32-35°C in the western (Gambella, Benishangul-Gumuz), southern Rift, and Somali lowlands, as well as in parts of Afar. The central and northern highlands remain much lower at 26-30°C.
- **Q2 (Apr-Jun):** Heat intensifies and spreads. A broad belt of very high WBGT extends across Afar and the eastern and southern lowlands, with pockets near or above 35-37°C. Highlands stay comparatively cooler, but begin to warm along valley corridors.
- **Q3 (Jul-Sep):** High heat stress persists in the north-east. The Afar Depression and adjacent lowlands show the highest values on the map, locally approaching 37-39°C, while the central highlands experience their lowest WBGT of the year, mostly 25-29°C, under the main rains.

- **Q4 (Oct-Dec):** Partial relief is evident in many regions, but elevated WBGT remains in the eastern and south-western lowlands. The plateau stays moderate, typically below 30°C, as rains retreat.

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



Spatial patterns

- **A strong elevation gradient** dominates all quarters. The central and northern highlands (Addis Ababa, Amhara, Tigray plateaus and much of Oromia's high ground) are consistently the least heat stressed.
- **The hottest zones** are the low-lying peripheries: Afar and the Awash valley, the Somali Region and southern Rift, the western borderlands of Gambella and Benishangul-Gumuz, as well as lowland pockets along major valleys.
- **Rift-valley corridors** stand out as warm passages extending into otherwise cooler highland areas, signalling local exposure for settlements and worksites along these corridors.
- **Urban centres** located in lowlands (e.g., Dire Dawa, Semera, Gambella, Assosa) are likely to face added heat from urban heat-island effects during the midday.

Implications for labour and OSH planning

- **Primary high-risk window:** Q2-Q3 in Afar, Somali, Gambella, Benishangul-Gumuz, and lowland Oromia/SNNP (Southern Nations, Nationalities, and Peoples' Region), where WBGT frequently exceeds 32-35°C and can reach 37°C or higher. Continuous moderate-to-heavy work is unsafe without strong protections. These provisions should be kept in place also during Q1 for the south-western lowlands, which remain hot early in the year.
- **Safer scheduling window:** Q3 across the central and northern highlands offers the coolest WBGT of the year. This is the best period for heat-exposed activities on the plateau, though site monitoring is still needed.
- **Sector focus:** Outdoor, high-exertion work (e.g., rain-fed and irrigated agriculture, pastoral herding, construction, road works, small-scale mining and quarrying, and logistics at lowland border posts) faces the greatest risk. Protections should be highest during Q2-Q3 in the lowlands.
- **Geographic targeting:** Prioritise Afar and adjacent valleys, the eastern and southern lowlands, and the western borderlands for heat-risk management and worker training. Maintain site-level WBGT monitoring in lowland cities where urban heat and low wind can create local hotspots.

Overall, the maps reveal that, while Ethiopia's highlands retain workable conditions for much of the year, the surrounding lowlands experience sustained, very high WBGT from late boreal spring through the summer monsoon. Policy and workplace measures should therefore be timed and targeted by WBGT, with the strongest protections concentrated in lowland regions especially during Q2-Q3.

2.3.1. Findings from comparing temperature against WBGT

Across quarters, lowland and humid zones register disproportionately higher WBGT than their air temperatures would suggest, while hot, drier inland areas look less extreme in WBGT relative to their temperature maxima. When comparing the maps showing environmental temperature against those illustrating the WBGT, the following key insights emerge:

Shared signals across both indicators

- **Strong elevation influence:** The central and western highlands stay much cooler/less stressful throughout the year, while the surrounding lowlands (Afar–Danakil to the northeast, Somali Region to the east and southeast, and the western and southwestern borderlands) register the highest values in all quarters.
- **The hottest season** by both air temperature and WBGT is Q2. Q3 shows the broadest cooling over the highlands with the main rains.
- **Afar stands out** in every quarter as a national hotspot in both metrics.

Where WBGT changes the picture

- **Humid vs dry heat:** In Q1, southwestern lowlands (Gambela-SNNP borderlands) show much higher WBGT than the air-temperature maps suggest, indicating humid heat. At the same time, the eastern lowlands are very hot by temperature but only moderate by WBGT, reflecting drier air and lower physiological strain than the (dry bulb) thermometer alone implies.
- **Monsoon season persistence:** Q3 is the coolest quarter on the temperature maps, but WBGT reveals persistent extreme stress in Afar/Danakil, with values frequently in the 33-37°C range and local maxima approaching ~39 °C. That is a level at which any kind of continuous moderate or heavy work becomes very quickly unsafe without strong controls.
- **Broader risk belt at mid-year:** In Q2, WBGT expands the high-risk areas beyond those flagged by temperature, pulling in large parts of the western lowlands and many escarpment foothills where moisture, calm winds, and high solar load coincide.

- **Rift and escarpment effects:** WBGT highlights hot corridors along rift/valley floors and lee slopes in several quarters that are not identified on the air temperature maps, pointing to combined humidity, solar, and low-wind effects.

Quarter-by-quarter contrasts

- **Q1.** Temperature: very high in Afar and the eastern/southeastern lowlands, while highlands remain much cooler. WBGT: peak stress shifts toward the southwestern lowlands. Afar shows high values but remains generally cooler than other quarters, while eastern lowlands are less severe than the temperature map implies.
- **Q2.** Temperature: national heat maximum, especially in Afar and the eastern lowlands. WBGT: widespread very high stress across Afar, western borderlands, and many foothills. The heat stress risk footprint is broader than the temperature map alone.
- **Q3.** Temperature: broad relief across the highlands during the rains, while peripheral lowlands remain hot. WBGT: Afar/Danakil remain at extreme heat levels, while the highlands experience their lowest stress and the southwestern lowlands ease compared with Q1-Q2.
- **Q4.** Temperature: warm-up in the lowlands, moderate in the highlands. WBGT: pockets of high stress re-emerge in the southwest and along some valley floors, while central highlands show mostly moderate heat levels.

Implications for labour and OSH planning

- **Use WBGT, not air temperature,** to trigger protections. Areas that look merely "hot" by air temperature can be at extreme-risk by WBGT when humidity and low wind raise the body's heat load.
- **Primary high-risk windows:** In Afar/Danakil, Q2-Q3 is the peak-risk season with heat at extreme levels. In southwestern lowlands, Q1 and Q2 show strong humid-heat and require, therefore, aggressive controls early in the year. The eastern lowlands are very hot by temperature, but risk is more season-dependent and WBGT-based protections should be applied, especially during Q2.
- **Best scheduling window:** The central and western highlands in Q3 offer the most reliable relief for heat-exposed work. Where feasible, outdoor and heavy tasks should advance into this season.
- **Controls to prioritise:** Mandatory water-rest-shade and extended mid-day breaks when WBGT exceeds ~32–33 °C. Protection measures should be applied for agriculture, construction, road and quarry work across lowlands in Q2-Q3. Local WBGT monitoring should be applied in rift/valley floors and urban centres such as Dire Dawa and Gambela, where pockets of high stress appear even when surrounding highlands are moderate.

Overall, air-temperature maps show locations that are hot, whereas WBGT shows where workers are most at risk. For Ethiopia, WBGT identifies a larger and more persistent hazard across Afar and the western/southwestern lowlands from Q2 through Q3, and a seasonal southwest peak in Q1 that the temperature maps understate. Planning and protections should follow WBGT thresholds and the quarter-specific risk patterns above.

2.4. Climate projections

2.4.1. Country overview

Ethiopia's climate over the past few decades has become warmer with high rainfall variability. The country remains vulnerable to climate shocks, with droughts occurring more often and intense rainfall events occasionally causing floods. These extremes have significant socio-economic impacts in a nation where many people rely on rain-fed agriculture and pastoralism. Below are the main impacts on key industries:

- **Agriculture:** Agriculture is the backbone of Ethiopia's economy, employing roughly two-thirds of the population and contributing about 34-40% of GDP.[29,30] However, it is overwhelmingly rain-fed and highly vulnerable to climate variability.[4] Droughts and unpredictable rainfall increasingly cause crop failures and livestock losses, undermining rural livelihoods and food exports.[4] For example, the 2020-2022 drought (the worst in 40 years) devastated harvests and pastoral lands, leaving over 20 million people severely food insecure in 2023.[4,7] Over 4 million livestock animals died in hard-hit regions,[31] crippling household incomes and pastoralist economies. Floods and unseasonal rain can also damage crops, underlying how extreme weather threatens agricultural output and farm income.[4,7] Additionally, climate-driven pest outbreaks (such as locust swarms following abnormal rain) have ravaged crops, compounding the sector's challenges.[4,7]

- **Mining and Industry:** Ethiopia's industrial sector (including mining, manufacturing, and construction, about 24.5% of GDP in 2023)[32] also faces climate-related stresses. Mining operations (for gold, potash, etc.) depend on water and stable weather; prolonged drought can constrain water-intensive mineral processing, while intense rainfall or floods can disrupt extraction and transport.[4] Manufacturing and agro-processing industries are indirectly affected by climate extremes through supply chain and power supply interruptions.[4] Notably, Ethiopia's electricity is predominantly hydropower (over 90% of generation),[33] so drought-induced water shortages have led to reduced power output and electricity rationing, slowing industrial productivity.[4] Planned expansion of hydropower (from ~3.7 GW in 2015 toward 19.5 GW by 2030) could be hampered by precipitation variability.[34,35] Extreme heat can also impact factory workers and equipment cooling, while floods can damage industrial zones and infrastructure.[4] Overall, climate shocks raise costs and uncertainties for Ethiopia's emerging industries.

- **Services:** The service sector (around one-third of GDP)[32] is not immune to climate impacts. Tourism, for instance, can suffer when droughts and ecosystem stress diminish wildlife and landscapes or when heritage sites are affected by heavy rains and erosion.[4] Communities around tourist sites may face water shortages, reducing hospitality services. In finance and retail services, climate disasters erode consumers' purchasing power and disrupt markets, particularly in rural towns.[4] Transport and trade services are affected when roads and logistics are cut off by floods or landslides, which are common in the rainy season.[4] Furthermore, recurrent climate emergencies divert government budgets to relief efforts, potentially reducing public investment in service industries.[4] While the services sector is growing, its stability and growth are intertwined with climate resilience in agriculture (which provides demand and inputs) and urban infrastructure (which is strained by floods and water scarcity).

Taken together, 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, indicating significant warming (Figure 4, top left graph), as well as

[29] Food and Agriculture Organization (2023). Scaling up climate ambition on land use and agriculture through Nationally Determined Contributions and National Adaptation Plans. https://www.fao.org/in-action/scala/countries/ethiopia/en. Accessed: 4/12/2024.
[30] ILIMS (2025). Ethiopia. Feed the Future Innovation Lab for Irrigation and Mechanization Systems, University of Nebraska. https://waterforfood.nebraska.edu/irrigandmech/work/ethiopia. Accessed: 13/1/2025.
[31] Concern Worldwide U.S. (2022). The Horn of Africa crisis, explained. https://concernusa.org/news/horn-of-africa-crisis-explained. Accessed: 4/12/2024.
[32] Statista (2026). Value added by economic sectors as a share of gross domestic product (GDP) in Ethiopia from 1981 to 2025. https://www.statista.com/statistics/455149/share-of-economic-sectors-in-the-gdp-in-ethiopia. Accessed: 26/2/2026.
[33] Worldometer (2016). Ethiopia Electricity. www.worldometers.info/electricity/ethiopia-electricity. Accessed: 4/12/2024.
[34] German Federal Ministry for Economic Cooperation and Development (2020). Climate Risk Profile: Ethiopia. Bonn, Germany.
[35] German Federal Ministry for Economic Cooperation and Development (2020). Climate Risk Analysis for Identifying and Weighing Adaptation Strategies in Ethiopia's Agricultural Sector. Bonn, Germany.

that warming has become more pronounced in Ethiopia 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 Ethiopia 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).

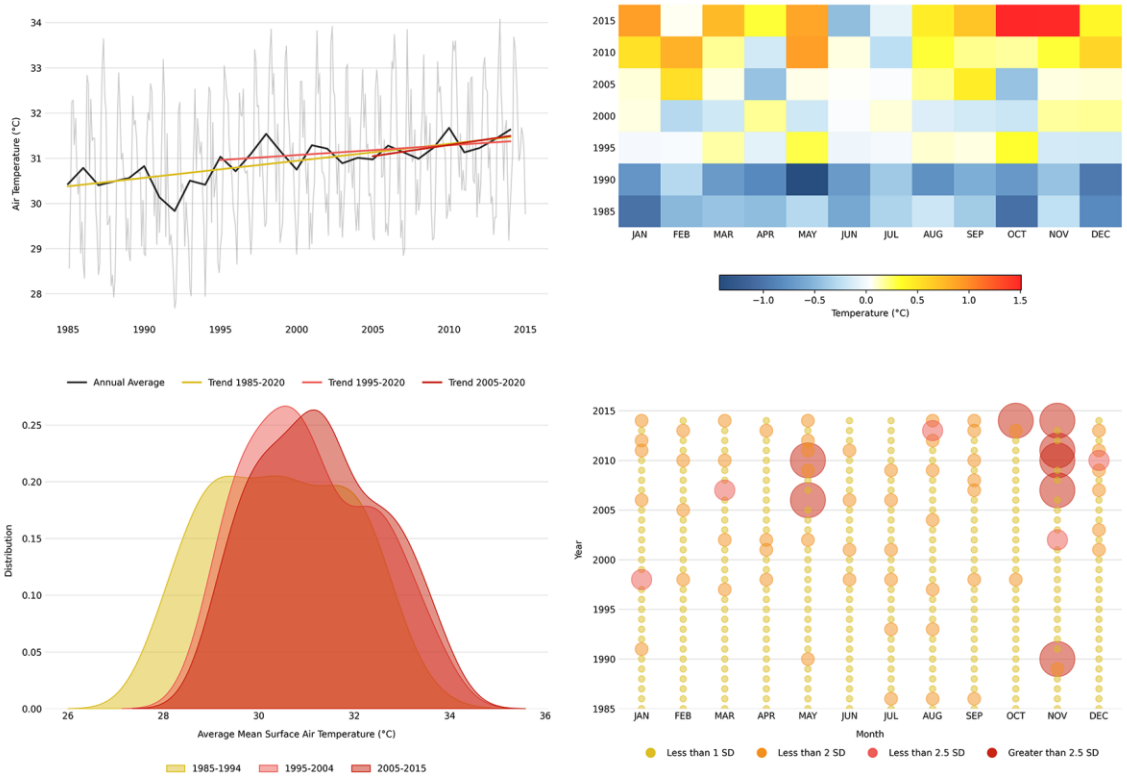
Collectively, the available evidence demonstrates a clear and accelerating warming trend in Ethiopia in the 30-year period until 2014:

- Average maximum temperatures have increased significantly, as indicated by the shift in distributions 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 Ethiopia, 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 Ethiopia'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 Ethiopia, with rural communities likely facing disproportionate challenges. Sectors such as agriculture and services, which are central to Ethiopia'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 Ethiopia 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 Ethiopia, the present study uses four "storylines" known as Shared Socioeconomic Pathways (SSPs). These scenarios were used by the IPCC Sixth Assessment Report[36] 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,[36] 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.

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.

[36] 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.[36] 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.

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 proceed 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 lifestyles. 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.[36]

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 Ethiopia 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 Ethiopia

While the SSPs are developed as global scenarios, they provide critical insights for national decision-makers, including those in Ethiopia. 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 Ethiopia, 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, Ethiopian 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 Ethiopia 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 Ethiopia 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 during the reference historical period (1985-2014) ranged between 30°C and 32°C, while the WBGT for the same period ranged between 29°C and 30°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), Ethiopia will face increases of 2-3°C environmental temperature and 2°C 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 5°C 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.

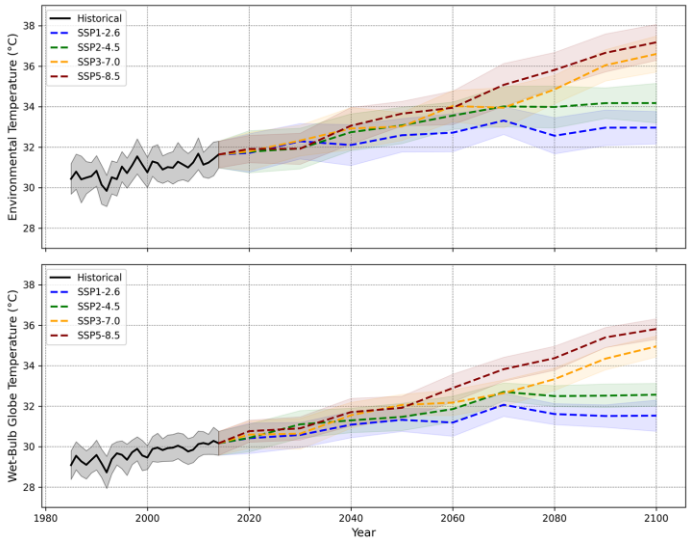
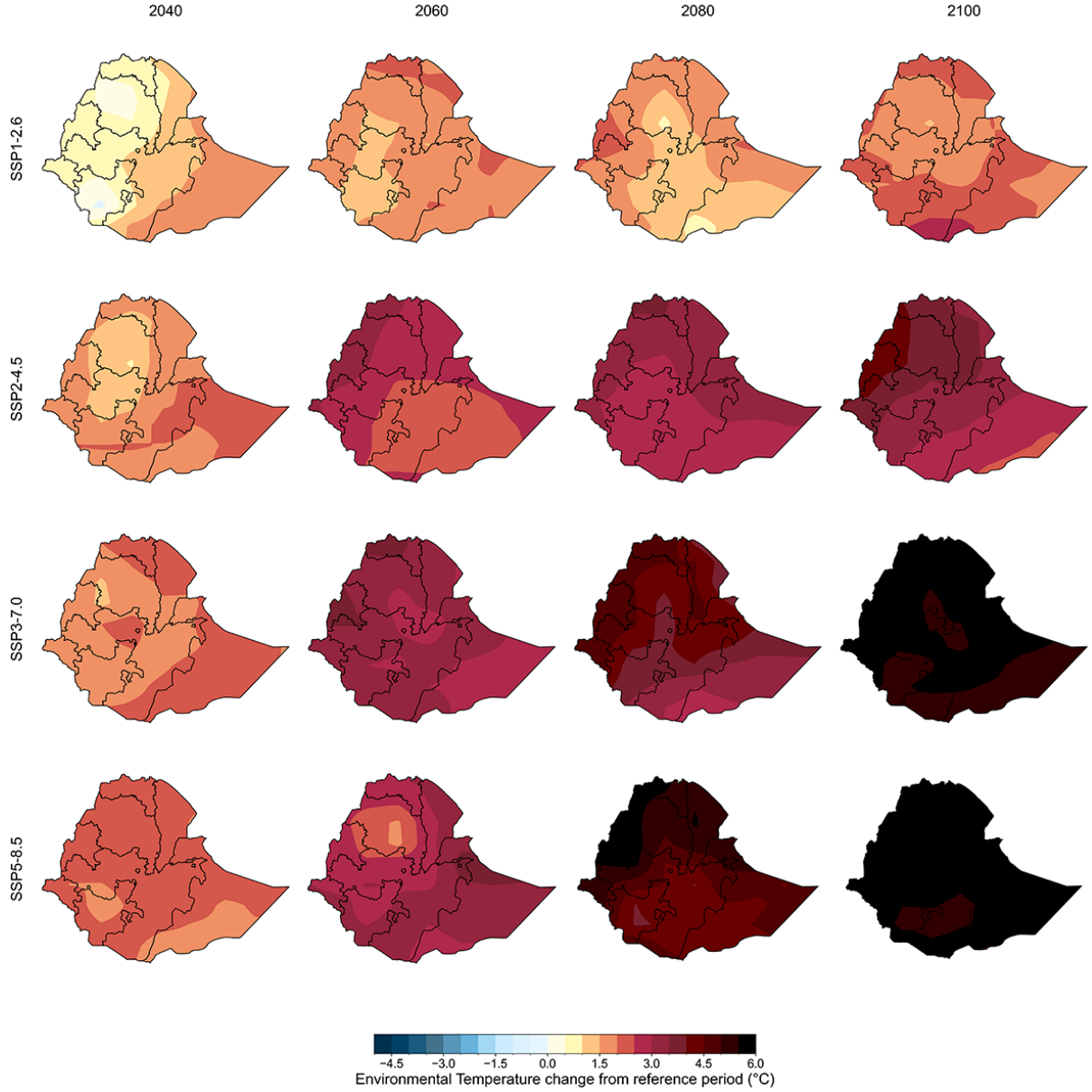


Figure 6 illustrates the change in environmental temperature compared to the reference historical period across the different SSPs and at different time points until the end of the century. The maps show a clear warming trend across Ethiopia in all scenarios and at every time step. By 2040 most areas will be about 1 to 2°C warmer than the 1985-2014 baseline. Differences between scenarios are small at that point. Under SSP1-2.6, the rise slows after 2050. By 2100, warming is about 2-2.5°C. Under SSP2-4.5, the increase continues and reaches roughly 3-4°C by century end. Under SSP3-7.0, the pace accelerates after mid-century and many regions approach 5°C by 2100. Under SSP5-8.5, much of the country reaches 6°C by 2080.

Warming is not uniform in space. Lowland areas warm more than the highlands throughout the 21st century. The Afar depression, the eastern lowlands, and parts of the south and southwest show earlier and stronger increases. The central and western highlands will warm less, but still move well above historical levels, especially in the higher emission scenarios.

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



The message is straightforward. A near term increase of 1 to 2°C is already certain and calls for planning around heat safety, work scheduling, and urban design. The choice of global pathway then determines the late-century burden. A path consistent with SSP1-2.6 avoids several degrees of extra warming compared with a high fossil fuel path. That gap translates into fewer days above critical heat thresholds at work and smaller losses in productivity and GDP (see Sections 3-5).

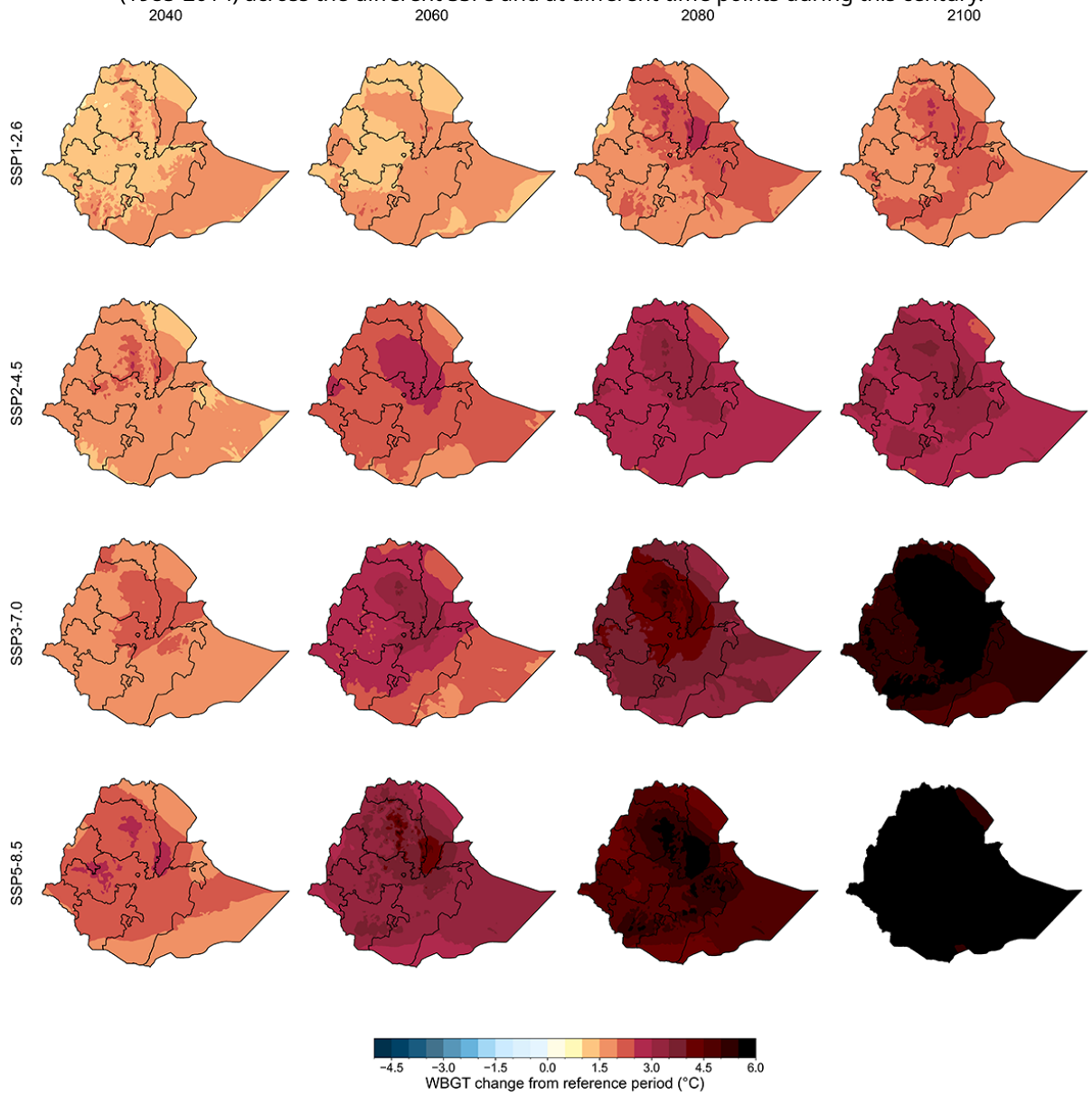
The change in WBGT compared to the reference historical period across the different SSPs and at different time points until the end of the century is illustrated in Figure 7. The maps show a steady rise in average maximum WBGT across Ethiopia in every future scenario. The increase is modest by 2040. Most regions are about 1 to 2°C warmer than the historical period. Differences between pathways are small at that time. After 2060 the paths separate. In SSP1-2.6 the rise slows and tends to level off near 2°C by 2100. In SSP2-4.5 many places climb toward 3 to 4°C by late century. In SSP3-7.0 and SSP5-8.5, the rise becomes steep. Large parts of the country reach 5 to 6°C above the historical period by 2100. That scale of change pushes many working days past safe limits for moderate and heavy tasks.

The spatial signal is consistent. The hottest and driest lowlands will warm the most. The Afar lowlands and the eastern and southeastern lowlands will heat up earliest and most strongly. The Rift Valley will also show large increases. The central and western highlands will warm less in relative terms, but the trend is still upward. Even the highlands will warm by 2°C under SSP1-2.6 and 5°C or more in the higher pathways by late century. By 2100 under SSP3-7.0 and SSP5-8.5, almost the whole country will experience 6°C warming, with the lowlands approaching the upper end of the scale.

These patterns have clear implications for work and health. A 1-2°C rise in WBGT already moves many days across key safety thresholds. The higher pathways imply many more hours when outdoor labour will be unsafe without strong protections. Northern and eastern lowlands will face the largest and earliest burden. The highlands will retain a relative advantage but will still see rising risk through the century.

Mitigation matters for labour outcomes. Keeping to a Paris aligned path will limit late century WBGT to roughly 2°C above the historical period. A high emissions path will raise that by four additional degrees. The gap by 2100 will be large, especially in the lowlands. Avoiding those extra degrees will prevent a sharp escalation in lost work time, heat illness, and GDP losses (see Sections 3-5).

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



3. Loss of work capacity by sector of activity

3.1. Overview of economic activity sectors

Ethiopia's economy comprises diverse sectors, each playing a significant role in the country's overall growth trajectory. The following overview highlights core industries, underlining their current contributions, key developments, and government policies shaping them. This snapshot focuses on recent trends, employment levels, sectoral share of GDP, and critical reforms underway, illustrating how Ethiopia's economic landscape is evolving. Together, these sectors form the basis for the country's ambitions toward structural transformation, improved productivity, and expanded export capacity, as outlined in Ethiopia's long-term development strategies.

1. **Agriculture:** Agriculture accounts for about 34-40% of GDP and employs roughly 63% of the labour force, making it the largest employer.[37] The sector grew by 6.3% in 2022-2023, but its share of GDP has gradually declined (from over 50% in 2000) as other sectors expand.[37] Productivity is improving slowly, yet agriculture remains mainly rain-fed and smallholder-dominated. Recurrent droughts and climate variability heavily impact outputs. Climate change is already affecting food security in the country. For example, Ethiopia's 2022 drought (the worst in 40 years) severely reduced harvests and left millions in need of aid.[4,7,31] The government prioritizes agriculture via its development plans. Initiatives focus on modernizing farming (e.g., improved seeds, irrigation) and building climate resilience under the Climate Resilient Green Economy strategy and National Adaptation Plan.[29] Programs such as the Agricultural Growth Program aim to boost productivity and exports of key commodities such as coffee, oilseeds, and pulses.[29]

2. **Construction:** The construction industry has grown rapidly and now contributes around 13-14% of Ethiopia's GDP,[37,38] reflecting a construction boom in infrastructure and urban development. It constitutes the largest component of the industrial sector. The sector is projected to grow by about 8% annually in the near term.[39] Massive public investments in roads, railways, dams (e.g., the Grand Ethiopian Renaissance Dam), and housing have driven construction growth,[39] while private real estate development is also on the rise, especially in cities. Construction is a major source of urban jobs and has upstream links to manufacturing of materials. The government reports that 80% of construction materials used are now supplied domestically, indicating growing local industry capacity.[39] Government policy heavily supports construction through its national development plans. A 10-year housing and infrastructure plan allocates significant budget to transport and energy projects, and the government encourages Public-Private Partnerships in construction. Officials emphasize the sector's "vital role" in job creation and economic transformation,[39] and regulatory frameworks (building codes, urban planning) are being updated to sustain growth and safety standards.

3. **Manufacturing:** Manufacturing remains relatively small, contributing only 6-7% of GDP and a modest share of employment.[37] Ethiopia's industrialization is at an early stage, with manufacturing meeting just 38% of domestic demand for industrial goods, the rest being imports.[40] The government has invested

[37] African Development Bank (2024). African Economic Outlook. Abidjan, Cote d'Ivoire.
[38] World Bank (2021). World Development Indicators database. https://databank.worldbank.org/views/reports/reportwidget.aspx?Report_Name=CountryProfile&Id=b450fd57&tbar=y&dd=y&inf=n&zm=n&country=ETH. Accessed: 4/12/2024.
[39] International Trade Administration (2024). Ethiopia - Country Commercial Guide. U.S. Department of Commerce. https://www.trade.gov/country-commercial-guides/ethiopia-market-overview. Accessed: 4/12/2024.
[40] Zekarias E. (2023). New report shows how Ethiopia's manufacturing sector can swing to benefit the economy. Capital Newspaper. https://capitalethiopia.com/2023/12/10/new-report-shows-how-ethiopias-manufacturing-sector-can-swing-to-benefit-the-economy. Accessed: 4/12/2024.

in industrial parks and attracted foreign manufacturers, particularly in textiles, apparel, leather goods, and agro-processing.[41] This led to growth in the late 2010s; however, recent shocks [COVID-19, internal conflict, and loss of the African Growth and Opportunity Act (AGOA) trade privileges] have slowed manufacturing growth. In 2022, output was affected by factory closures and investor exits, and manufacturing's GDP share dipped to about 5%.[41] Despite these setbacks, export-oriented factories in industrial parks are gradually resuming operations, and industrial park exports rose by about 16% in 2024.[42,42] As manufacturing is a cornerstone of Ethiopia's economic strategy, the government established 18 industrial parks (13 public, 5 private) to attract investment under the Growth and Transformation Plans and the current 10-Year Development Plan.[41] These parks have drawn over 60 foreign firms and created around 150,000 jobs to date.[41] Policies offer tax incentives and infrastructure to manufacturers. The government's "Homegrown Economic Reform" agenda also targets improvements in the business climate (e.g., easing import of inputs and access to finance) to boost the manufacturing sector. Overall, Ethiopia aims to become a light manufacturing hub in Africa and increase manufactured exports significantly by 2030,[41] though this will require overcoming current challenges and sustaining political stability.

4. **Mining and extractives:** The extractive sector is very small in Ethiopia. Mining and quarrying account for roughly 1% of GDP and about 1% of official export earnings.[43] The sector's contribution to employment is also low in formal terms, though artisanal mining (gold panning, salt mining) provides informal livelihoods in some regions.[44] Gold is the primary mineral export, constituting about 15% of Ethiopia's goods exports in 2021.[40] Gold production comes from both large-scale mines and artisanal miners. Other mineral resources include opals and gemstones, tantalum, potash, and quarry materials such as limestone. The government is seeking to develop the mining sector to diversify the economy. Ethiopia joined the Extractive Industries Transparency Initiative in 2014 to improve governance.[44] Mining laws have been revised to offer tax incentives and licensing transparency to attract foreign investment and efforts are underway to formalize artisanal mining and curb smuggling (especially of gold).[44] Overall, while current output is small, the government identifies mining as a growth opportunity and is investing in geological surveys and mining infrastructure to increase its future contribution.

5. **Services:** Services have overtaken agriculture as the largest sector, accounting for about 40% of GDP and roughly 30% of employment.[37] The service sector grew by 7.9% in 2022-2023, led by expansion in communication, transport, trade, and hospitality services.[37] Finance contributes around 3-4% of GDP, but this share is expected to grow with new entrants and investment. The information and communication technology sub-sector is rapidly evolving and telecom subscriber numbers and internet access are rising as a result.[40] The government is also investing in parks and digital infrastructure, recognizing the sector's importance for innovation and job creation. Tourism is an important and growing part of the service sector. Pre-pandemic, in 2019, tourism contributed about 4.8 USD billion to GDP (around 4% of GDP) and international arrivals peaked at over 1.4 million visitors.[45] However, the COVID-19 pandemic and recent conflicts caused a sharp downturn: international tourist arrivals fell by over 80% in 2020,[46] and the Tigray conflict further hurt the country's image. With the peace agreement in late 2022 and global travel rebounding, tourism is recovering, with the 2023 receipts remaining only

[41] African Development Bank (2024). Ethiopia Country Focus Report. Abidjan, Cote d'Ivoire.
[42] Cepheus Research and Analytics (2020). Ethiopia's Industrial Parks: A Data Pack on recent performance. https://cepheuscapital.com/wp-content/uploads/2020/09/Industrial-Parks-Overview-2019-20.pdf. Accessed: 4/12/2024.
[43] Ethiopian Ministry of Mines and Petroleum (2021). Ethiopian Extractive Industries Transparency Initiative. EEITI final report for year ended 7 July 2019. https://eiti.org/documents/ethiopia-20182019-eiti-report. Accessed: 4/12/2024.
[44] Abate Demissie A., Soliman A. (2024). Illicit gold is exacerbating Ethiopia's conflicts. Chatham House, The Royal Institute of International Affairs. https://www.chathamhouse.org/2024/09/illicit-gold-exacerbating-ethiopias-conflicts. Accessed: 4/12/2024.
[45] Remarks of the ECA SRO-EA Director on the occasion of the launch of Ethiopia Tourism Satellite Account (2024). Addis Ababa, Ethiopia. https://www.uneca.org/stories/launch-of-ethiopia-tourism-satellite-account-remarks-by-geoffrey-manyara%2C-eca-eastern-africa. Accessed: 4/12/2024.

~6% below 2019 levels.[46] The government has launched campaigns to promote tourism and is improving tourist facilities. Given Ethiopian Airlines' large African network, Addis Ababa has become a regional air travel hub which supports tourism.[46] The outlook is positive as stability improves, though full recovery to pre-crisis levels may take two additional years.

6. **Transportation and trade:** Ethiopia's transport and communications sector contributes roughly 5.8% of national GDP and employs 2-3% of the workforce.[42] On the other hand, trade accounts for about 14.6% of Ethiopia's GDP and provides approximately 6% of total employment in Ethiopia.[42,47] Ethiopia has invested heavily in transport infrastructure. The road network has expanded from about 27,000 km in 1997 to over 144,000 km of all-weather roads by 2020, improving connectivity across the country.[40] Major highways now link key cities and neighboring countries. Ongoing projects aim to further expand road coverage, with a target of ~245,000 km by 2030.[40] In rail, the country commissioned a new standard-gauge railway: the Addis Ababa–Djibouti electrified railway (656 km), operational since 2018. This railway has dramatically cut freight transport time from the capital to the sea (Djibouti) from about 84 hours to 10 hours, boosting efficiency for import-export trade.[40] Addis Ababa also introduced a light rail transit system, the first modern light rail in sub-Saharan Africa, to ease urban transport. Regarding air transport, Ethiopian Airlines, a state-owned carrier, is Africa's largest airline and has made Addis Ababa a regional aviation hub.[47] The government is planning a new mega-airport to accommodate future growth. Domestic air connectivity has also improved, with Ethiopian Airlines and private carriers serving many secondary cities. In 2020, Ethiopia adopted a National Transport Policy and a comprehensive 10-year transport sector plan (2020-2030). The plan calls for about 3 trillion birr (~58 USD billion) investment in transport infrastructure over 10 years.[40] Also, the government is opening transport to private investment, forming a National Transport Council to facilitate Public-Private Partnerships. Overall, transportation has seen robust growth due to public spending, and continued expansion is critical for Ethiopia's economic integration and development.

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.[26] These responses become particularly significant in occupational settings where physical work is required.

[46] U.K. Department for Business & Trade (2025). Guidance: Doing business in Ethiopia. https://www.gov.uk/government/publications/doing-business-in-ethiopia-guidance-on-exporting-and-business-risks/doing-business-in-ethiopia. Accessed: 14/2/2025.
[47] Danish Trade Union Development Agency (2024). Ethiopia Labour Market Profile – 2024/2025. Copenhagen, Denmark.

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.[27] 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.[27,48]

Work intensity and metabolic heat production

The physical effort required for high-intensity work naturally produces metabolic heat.[27,49] When this internal heat generation combines with external (environmental) heat stress, the body's cooling mechanisms can be overwhelmed.[27] 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"[28] and it is a key factor in the observed loss of work time and, therefore, productivity.[50]

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[51,51] and increased error rates.[52] This occurs because workers should take more frequent breaks, reduce their pace, or even stop working to avoid heat-related health risks.[53] 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.[25,52]

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 Ethiopia was estimated using a response function for workability, based on previous methods.[54] The estimated work capacity loss in Ethiopia'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 between 28-32% in high-intensity work, between 15% and 19% in moderate-intensity work, and between 6% and 9% in

[48] Kenny G.P., Wilson T.E., Flouris A.D., Fujii N. (2018). Heat exhaustion. Handbook of Clinical Neurology; 157: 505-529.
[49] 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.
[50] 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.
[51] 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.
[52] 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.
[53] 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.
[54] 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.

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 12-22% in high-intensity work, 11-20% in moderate-intensity work, and 6-12% in low-intensity work, reflecting relatively mild impacts due to strong climate change mitigation. In SSP3-7.0 and SSP5-8.5, climate change will lead to additional work capacity losses reaching 40% across the different work intensities by 2100, reflecting the severe impact of climate change and heat stress on work capacity. These are the most pessimistic emission scenarios, showing the highest projected losses, reflecting the severe impact of climate change and heat stress on work capacity.

In **manufacturing**, **mining and quarrying** (Figure 9), **services**, as well as **transportation and trade** (Figure 10), work capacity losses remained below 10% during the historical period. During the 21st century, climate change under SSP1-2.6 and SSP2-4.5 is not expected to cause significant work capacity losses in low- and moderate-intensity work beyond the levels observed in the historical period. However, in high-intensity work under scenarios SSP1-2.6 and SSP2-4.5, climate change will cause additional work capacity losses of 5-12%. Moreover, in SSP3-7.0 and SSP5-8.5, climate change will lead to additional work capacity losses reaching 10% in low-intensity work, 20% in moderate-intensity work, and exceeding 30% 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 projected losses under all scenarios. Although the impact on moderate- and low-intensity work is less severe, even these activities will experience work capacity declines, particularly under higher-emission scenarios, highlighting the pervasive impact of rising heat levels.
- **Vulnerability is unequal:** agriculture and construction show the highest work capacity losses due to increased heat stress from climate change, reaching as high as 40% by the end of the century. 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), 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 Ethiopia.

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

Figure 8. Average work capacity loss (%) in Ethiopia 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.

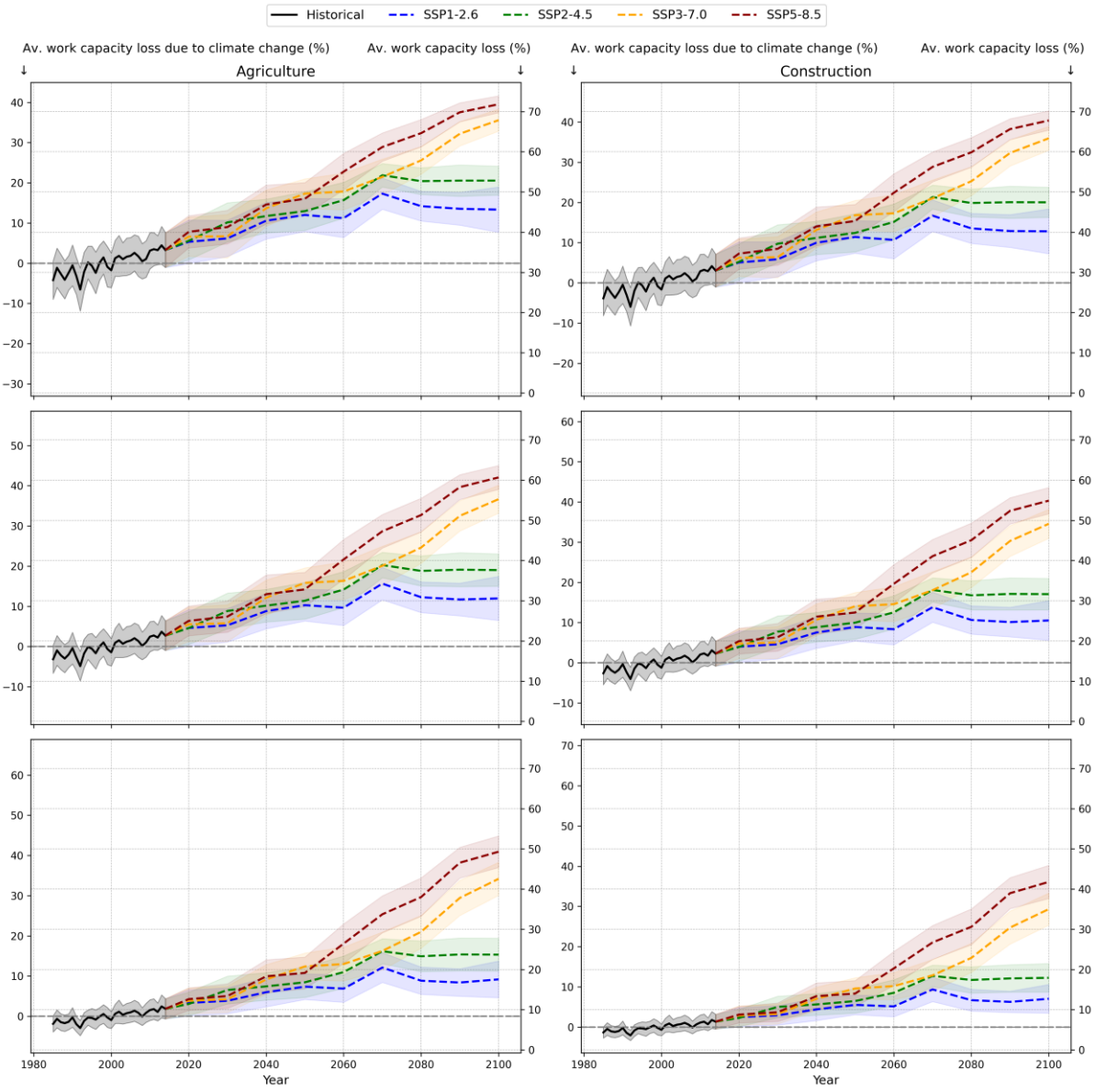


Figure 9. Average work capacity loss (%) in Ethiopia during high- (top), moderate- (middle), and low- (bottom) intensity work in manufacturing (left graphs) as well as mining and quarrying (right graphs) during the reference historical period (1985-2014) and until 2100 across the different SSPs. Vertical 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.

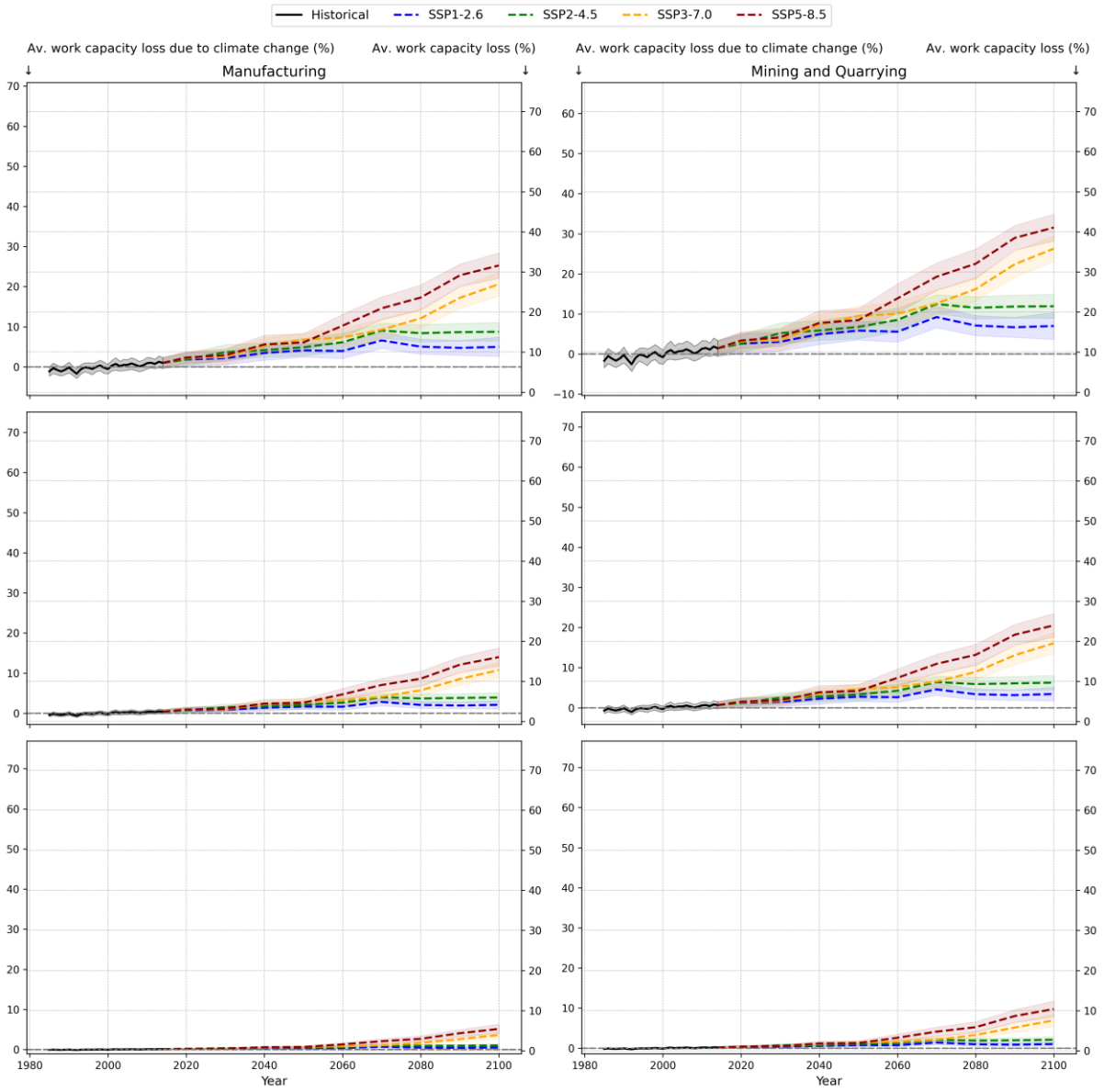
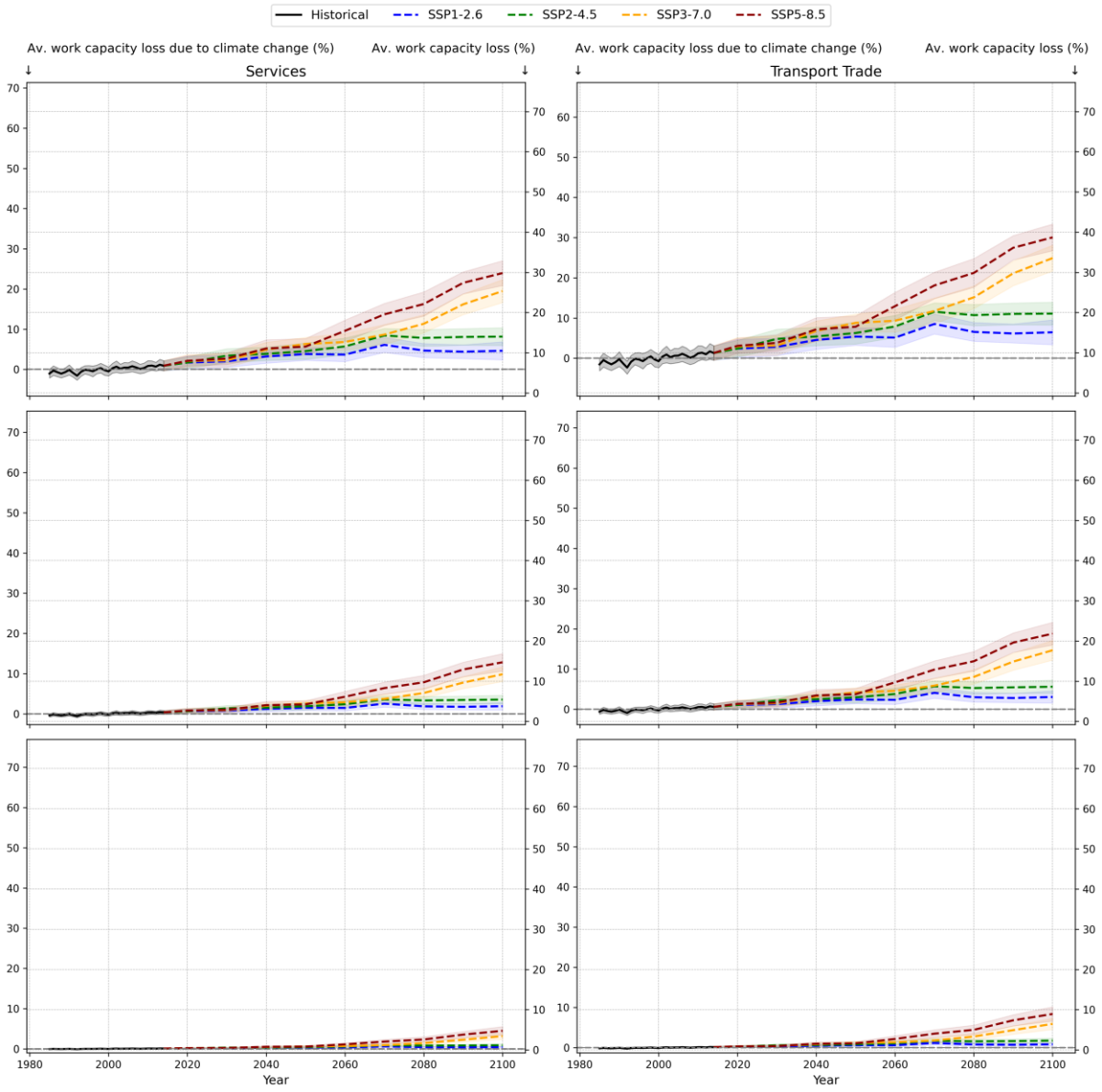


Figure 10. Average work capacity loss (%) in Ethiopia during high- (top), moderate- (middle), and low- (bottom) intensity work in services (left graphs) as well as transportation and trade (right graphs) during the reference historical period (1985-2014) and until 2100 across the different SSPs. Vertical 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.



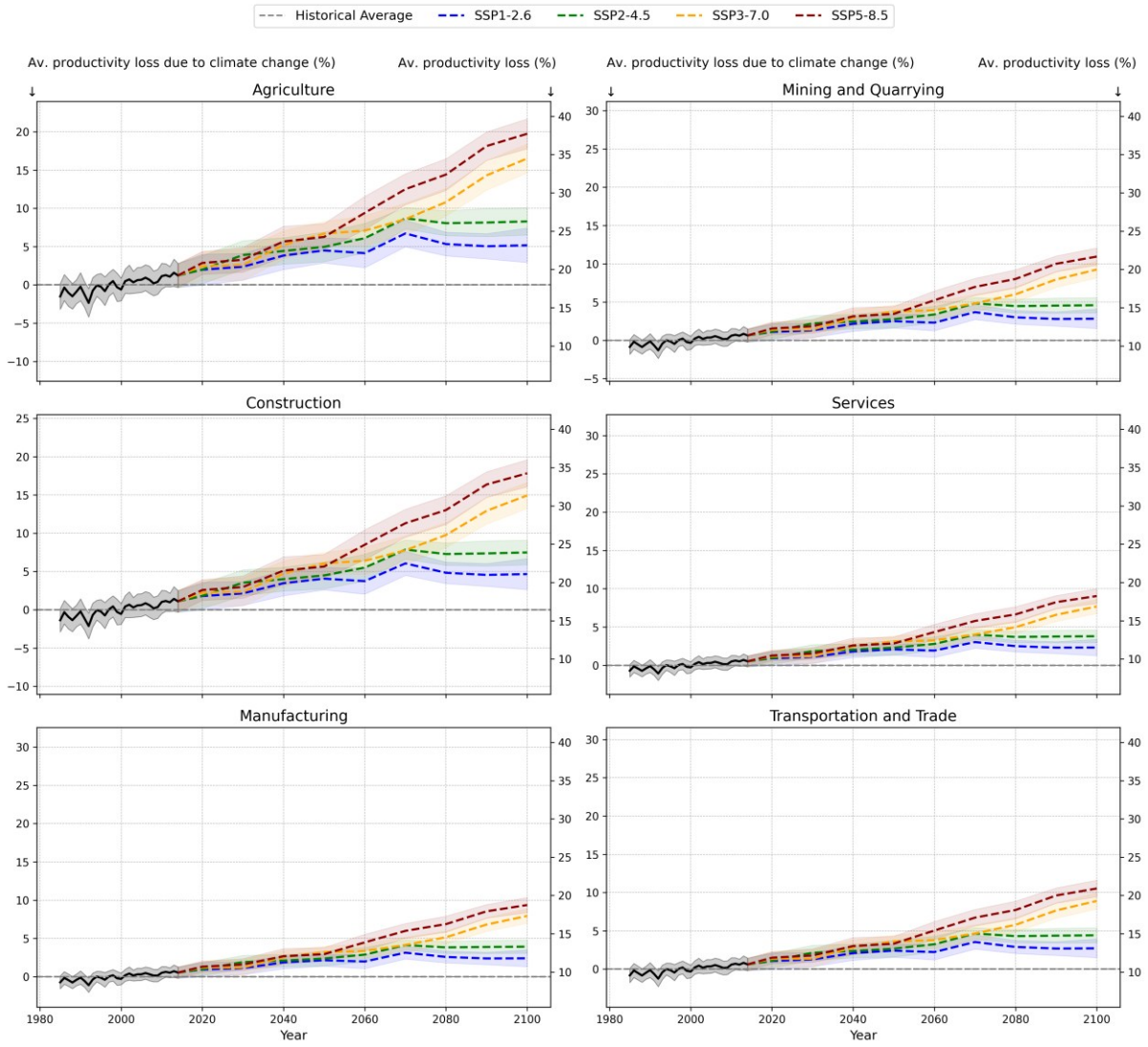
4. Loss of productivity by sector of activity

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.[25,52,53,54] 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 16% and 18%, during the historical period. By 2100, under SSP1-2.6 and SSP2-4.5, productivity loss is expected to further increase by 5-9% 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 20% 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 9% to 11% during the historical period. Under SSP1-2.6 and SSP2-4.5, climate change is anticipated to further increase productivity loss by 2-5% 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 11% in these scenarios by 2100, compared to the average year within the reference period.

Figure 11. Average productivity loss in Ethiopia 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 (right hand side axis) and productivity 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.



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 Ethiopia lost 8 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 shows that climate change impacts on GDP cluster around the main urban and industrial hubs. The largest hotspot is located in and around Addis Ababa. Regional centers also stand out, including Dire Dawa in the east, Hawassa and Adama along the Rift Valley corridor, and cities in Amhara and Tigray. A smaller but clear cluster appears in the southeast Somali region. Most rural districts show lower absolute losses because they produce less output per square kilometer, not because workers are safe from heat.

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	-3,139.7	39.1
Construction	-1,828.6	22.8
Manufacturing	-305.0	3.8
Mining and Quarrying	-86.4	1.1
Services	-2,231.1	27.8
Transport and Trade	-428.9	5.4
Total GDP change	-8,019.8	

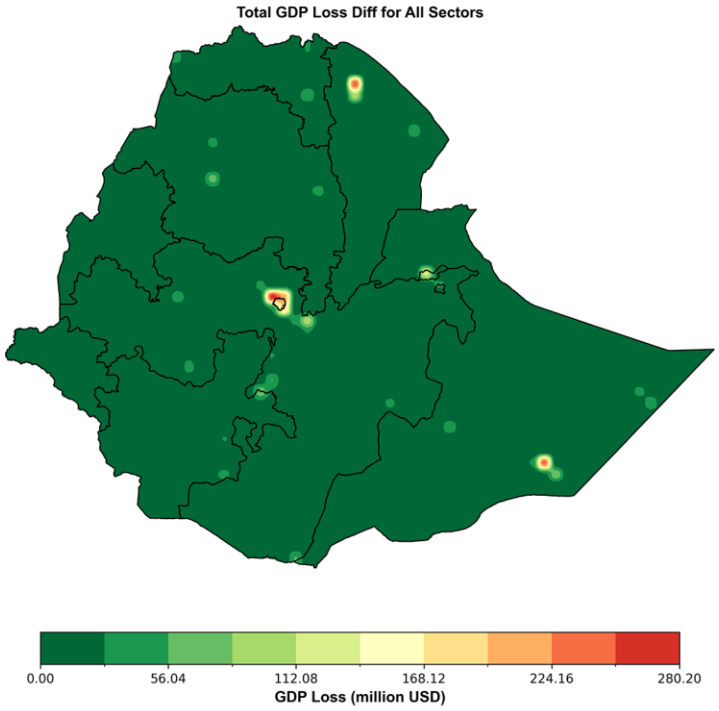
* million USD (fixed 2015 prices), with negative values indicating a GDP reduction compared to the baseline historical period 1985-2014.

The pattern reflects where people and firms are concentrated. When heat reduces work time during the hottest hours, the GDP loss is highest where value added and employment are densest. Urban heat island effects and warm indoor workplaces add to the burden. Lower values elsewhere should not be read as low risk. Agricultural

and informal workers across the lowlands face high exposure, but the absolute loss is smaller because the local economy is smaller.

The policy message is direct: Protect workers and firms in Addis Ababa and the main regional hubs. Focus on efficient cooling, ventilation, shade, water, and flexible hours. Use WBGT based work rest rules during hot periods. Extend similar protection to rural districts for outdoor work. This will reduce current losses and prevent larger losses as heat rises.

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



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 39.1% of the additional GDP losses compared to an average year during the historical period. Services are also heavily impacted, with 2.2 billion more USD lost due to heat stress during 2023 in relation to an average year during the historical period (Table 2). Construction is also heavily impacted, representing 22.8% 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. The maps indicate that losses are concentrated in a few urban and industrial centres. Addis Ababa stands out across most sectors. Smaller hotspots appear along the main corridor to Djibouti and around several regional hubs. Most districts record small absolute losses because their economic base is smaller.

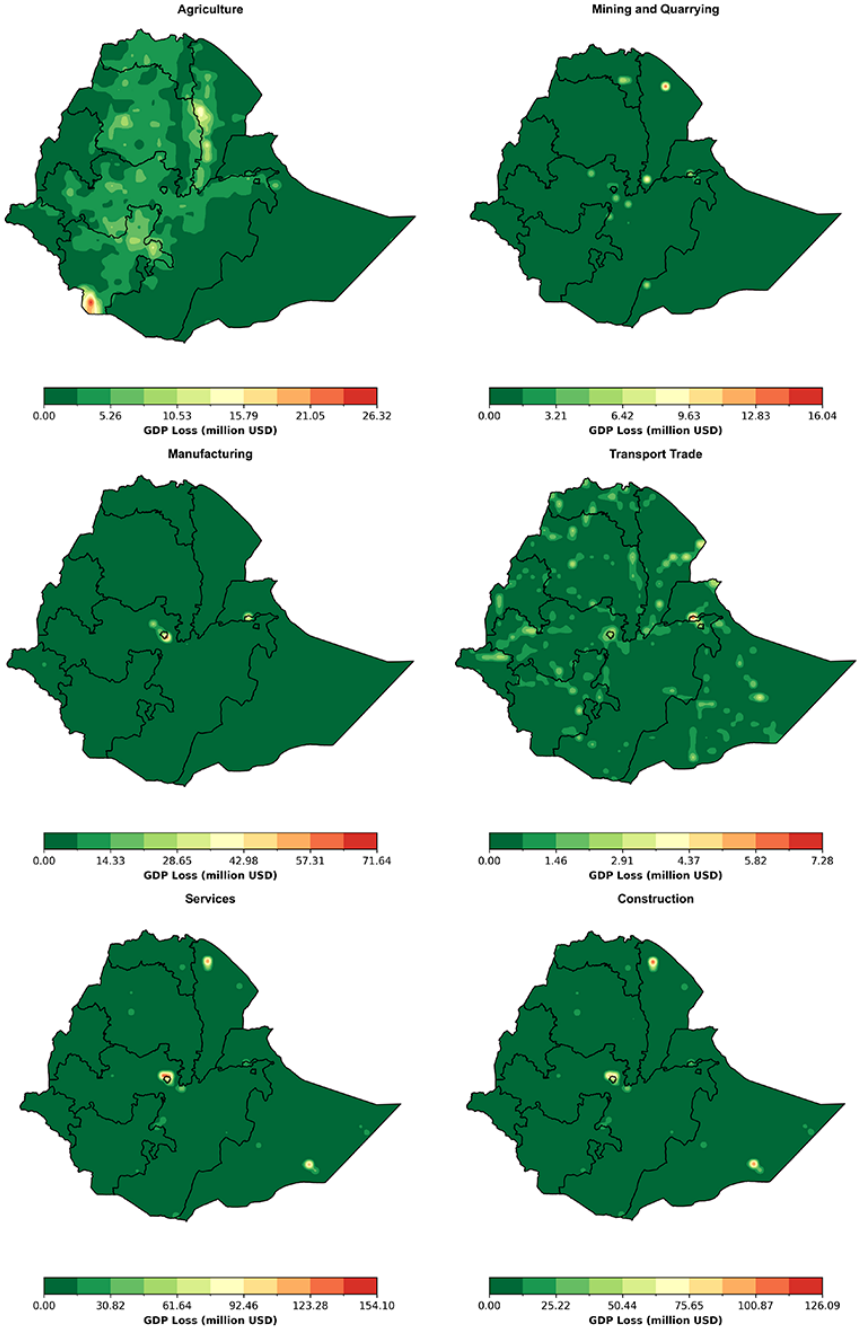
Services carry the largest absolute loss. The peak loss occurs in and around Addis Ababa and reaches about 150 million USD. Smaller hotspots appear near other cities. This reflects the concentration of retail, hospitality, public

administration and other service activities in urban areas where mid-day heat cuts work time. Manufacturing losses are tightly clustered. They are highest around Addis Ababa and nearby industrial zones. Losses reach roughly 70 million USD at the local peaks, pointing to the sensitivity of workshop and factory work where cooling and ventilation are limited.

Construction shows clear urban hotspots. Addis Ababa again dominates, with losses reaching about 125 million USD. Project sites along major corridors also register losses. Outdoor work and rigid timelines make the sector vulnerable during the hottest hours. Agriculture losses are more spread out across the highlands and Rift Valley. The absolute loss per district is smaller than in services, with local peaks around 25 million USD, but the effect on rural incomes can still be significant because many tasks are manual and outdoors. Transport and trade show many small nodes along the highway network and at logistics hubs. Local losses are modest in absolute terms, up to about 7 million USD, yet delays and reduced throughput can ripple through supply chains. Finally, mining and quarrying losses are site specific. They appear at a handful of locations with peaks near 16 million USD. While the national total is relatively small, the local impact can be large where a mine dominates the local economy.

A technical note is important. Colour scales differ by panel to preserve detail, so intensities should not be compared across sectors. The consistent message is that losses are largest where output and employment are most concentrated, especially in and around Addis Ababa. Rural and corridor areas also face meaningful losses in sectors that rely on outdoor or high-exertion work. This pattern points to priority locations for heat management and to sector measures that protect work during the hottest hours.

Figure 13. GDP loss across Ethiopia 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 Ethiopia'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. Ethiopia'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 8.8% and 9.2% 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 33.3 billion USD in 2040 and 158.4 billion USD in 2060. Under a "middle-of-the-road" scenario (SSP2-4.5), the contraction deepens from 9.2% (29.9 billion USD) in 2040 to 10.2% (139.2 billion USD) in 2060, while a regional-rivalry world (SSP3-7.0) will drastically increase the burden to 10.7% by 2060. Given the slow economic growth foreseen in SSP3 (see Section 2.4.2), this higher relative loss is equal to 79.4 billion USD. Should fossil-fuel development continue unabated (SSP5-8.5), rising workplace heat stress could cut 12.4% (310.3 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. Agriculture, the backbone of the Ethiopian economy, bears most of the losses: 4.9% of GDP (18.7 billion USD) more losses in 2040 under SSP1-2.6 compared to the historical period, rising to 6.8% (170.1 billion USD) in 2060 under SSP5-8.5. Manufacturing absorbs steady declines that deepen from 0.4% (SSP1-2.6, 2040) to 0.6% (SSP5-8.5, 2060), reflecting high indoor heat loads and partial air-conditioning coverage. Services will record declines that deepen from 1.7% of GDP (SSP1-2.6, 2040) to 2.5% (SSP5-8.5, 2060). The latter is equal to 61.5 billion USD, inflicting a major impact on Ethiopia's GDP. Similarly, construction will experience 1.2% (4.6 billion USD) more losses in 2040 under SSP1-2.6 compared to the historical period, rising to 1.8% of GDP (45.3 billion USD) in 2060 under SSP5-8.5. Mining and quarrying are expected to experience small and steady climate change impacts ranging from 0.05% of GDP (0.2 billion USD) additional losses in 2040 (compared to the baseline period), to 0.08% of GDP (2 billion USD) in 2060.

Three policy conclusions follow. First, the steep scenario gradient confirms that ambitious global mitigation (SSP1-2.6) could avert 3.24 percentage points of GDP loss by 2060 (about 152 billion USD in 2060), relative to SSP5-8.5. Second, domestic adaptation should prioritise heat-proofing the services economy, particularly retail, hospitality, and public administration, where the absolute loss is highest (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 transport and trade as well as manufacturing and construction will intensify exposure to workplace heat stress. Therefore, integrating heat stress thresholds into building codes, transport and agricultural extension services, as well as social-protection schemes will be critical. Anchoring these measures in Ethiopia's forthcoming National Adaptation Plan and Decent Work Country Programme will help safeguard both competitiveness and worker welfare as temperatures rise.

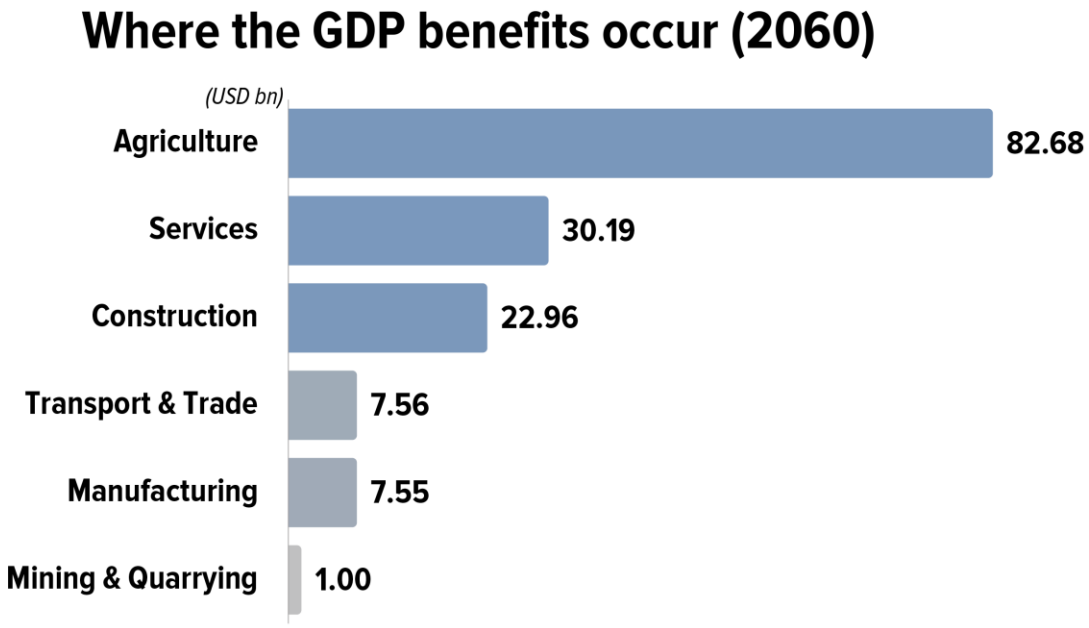
Table 3. Annual impact of rising workplace heat stress caused by climate change on GDP in Ethiopia during 2040 and 2060 across different SSPs, compared to the baseline historical period 1985-2014.

		Change in GDP			
		2040		**2060**	
		(M USD)[1]	*(%)*	*(M USD)*[1]	*(%)*
Agriculture	SSP1-2.6	-18,681.7	-4.93	-87,434.5	-5.05
	SSP2-4.5	-16,658.3	-5.09	-74,776.3	-5.50
	SSP3-7.0	-13,218.4	-5.11	-41,359.9	-5.57
	SSP5-8.5	-27,075.8	-5.68	-170,115.4	-6.79
Construction	SSP1-2.6	-4,612.8	-1.22	-22,310.4	-1.29
	SSP2-4.5	-4,269.4	-1.30	-20,617.6	-1.52
	SSP3-7.0	-3,519.5	-1.36	-12,342.8	-1.66
	SSP5-8.5	-6,825.1	-1.43	-45,271.3	-1.81
Manufacturing	SSP1-2.6	-1,572.8	-0.42	-7,768.2	-0.45
	SSP2-4.5	-1,443.0	-0.44	-7,306.0	-0.54
	SSP3-7.0	-1,207.2	-0.47	-4,434.1	-0.60
	SSP5-8.5	-2,236.8	-0.47	-15,323.0	-0.61
Mining and Quarrying	SSP1-2.6	-187.9	-0.05	-1,020.0	-0.06
	SSP2-4.5	-169.0	-0.05	-927.7	-0.07
	SSP3-7.0	-138.0	-0.05	-552.8	-0.07
	SSP5-8.5	-274.4	-0.06	-2,023.7	-0.08
Services	SSP1-2.6	-6,385.8	-1.69	-31,327.9	-1.81
	SSP2-4.5	-5,762.3	-1.76	-28,203.9	-2.07
	SSP3-7.0	-4,711.2	-1.82	-16,596.5	-2.24
	SSP5-8.5	-9,169.6	-1.92	-61,521.7	-2.46
Transport and Trade	SSP1-2.6	-1,826.7	-0.48	-8,507.1	-0.49
	SSP2-4.5	-1,630.2	-0.50	-7,315.7	-0.54
	SSP3-7.0	-1,318.4	-0.51	-4,095.5	-0.55
	SSP5-8.5	-2,577.5	-0.54	-16,065.3	-0.64
TOTAL	SSP1-2.6	-33,267.7	-8.78	-158,368.1	-9.15
	SSP2-4.5	-29,932.2	-9.15	-139,147.2	-10.23
	SSP3-7.0	-24,112.8	-9.32	-79,381.5	-10.69
	SSP5-8.5	-48,159.2	-10.11	-310,320.4	-12.38

[1] million USD, fixed 2015 prices.

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

Infographic 1. Sectoral GDP benefits of implementing in Ethiopia 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).



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 Ethiopia'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 in Table 4 show that the impact of climate change on Ethiopia's labour market is significant, with over one million more jobs lost due to workplace heat stress during 2023 compared to the average year during the historical period. Nearly 75% of job losses are concentrated in agriculture, 19% occur in services, as well as

about 2.5%, 1.7%, and 1.1% in construction, manufacturing, as well as transport and trade, respectively (Table 4 and Infographic 2). The analysis also reflects a seasonal pattern where 30.3% of the impacts occur in Q2 and 29.5% in Q1, reflecting the parts of the years with peak heat levels. 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 Ethiopia.

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 Ethiopia, calculated as the change between 2023 and the reference historical period 1985-2014.

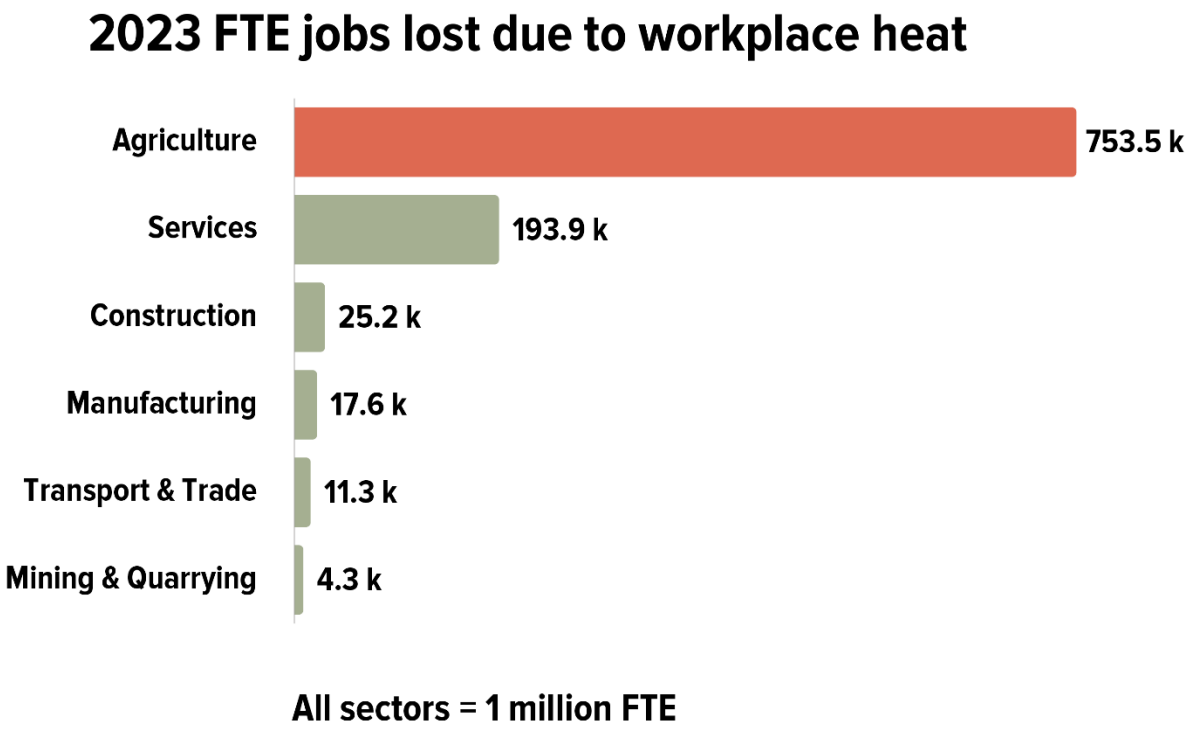


Table 4. Quarterly and annual impact of rising heat stress due to climate change on full-time equivalent jobs lost (proxied from work hours lost) in each sector of economic activity and across the entire economy in Ethiopia, calculated as the change between 2023 and the reference historical period 1985-2014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

Sector	Period	Available Work Hours (n)	Change in Work Hours		Change in Jobs (FTE)
			(n)	(% FTE)	
Agriculture	Q1	17,911,636,063	-453,355,637	-2.53	-226,000
	Q2	18,118,707,000	-469,523,015	-2.59	-234,059
	Q3	18,325,777,937	-318,202,424	-1.74	-158,625
	Q4	18,325,777,937	-270,493,820	-1.48	-134,842
	Year	72,681,898,937	-1,511,574,896	-2.08	-753,527
Construction	Q1	594,821,946	-14,097,417	-2.37	-7,028
	Q2	601,698,500	-15,261,709	-2.54	-7,608
	Q3	608,575,054	-11,560,747	-1.90	-5,763
	Q4	608,575,054	-9,563,572	-1.57	-4,767
	Year	2,413,670,554	-50,483,446	-2.09	-25,166
Manufacturing	Q1	912,658,040	-10,345,459	-1.13	-5,157
	Q2	923,209,000	-9,485,459	-1.03	-4,729
	Q3	933,759,960	-8,141,969	-0.87	-4,059
	Q4	933,759,960	-7,312,284	-0.78	-3,645
	Year	3,703,386,960	-35,285,172	-0.95	-17,590
Mining and Quarrying	Q1	157,616,840	-2,378,771	-1.51	-1,186
	Q2	159,439,000	-2,401,642	-1.51	-1,197
	Q3	161,261,160	-2,181,340	-1.35	-1,087
	Q4	161,261,160	-1,636,915	-1.02	-816
	Year	639,578,160	-8,598,667	-1.34	-4,286
Services	Q1	8,471,106,631	-108,568,225	-1.28	-54,122
	Q2	8,569,038,500	-108,393,112	-1.26	-54,034
	Q3	8,666,970,369	-89,887,909	-1.04	-44,810
	Q4	8,666,970,369	-82,069,084	-0.95	-40,912
	Year	34,374,085,869	-388,918,331	-1.13	-193,878
Transport and Trade	Q1	477,835,391	-6,883,696	-1.44	-3,432
	Q2	483,359,500	-6,725,900	-1.39	-3,353
	Q3	488,883,609	-4,775,494	-0.98	-2,381
	Q4	488,883,609	-4,330,330	-0.89	-2,159
	Year	1,938,962,109	-22,715,421	-1.17	-11,324
TOTAL	Q1	28,525,674,911	-595,629,206	-2.09	-296,924
	Q2	28,855,451,500	-611,790,838	-2.12	-304,980
	Q3	29,185,228,089	-434,749,883	-1.49	-216,725
	Q4	29,185,228,089	-375,406,006	-1.29	-187,142
	Year	115,751,582,589	-2,017,575,932	-1.74	-1,005,771

n: number; FTE: full-time equivalent.

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 productivity losses attributable to climate-induced heat stress grow markedly with the global emissions trajectory and are already substantial for Ethiopia by 2040. Estimates indicate that, relative to the 1985-2014 baseline, the economy will lose the equivalent of 1.78 million full-time jobs under a low-emissions pathway (SSP1-2.6). The losses rise to nearly 2.45 million full-time jobs under SSP2-4.5 and reach 2.77-3.06 million under the high-emissions scenarios (SSP3-7.0 and SSP5-8.5). In proportional terms this represents 5% contraction in total labour force under the most optimistic scenario and nearly 8% under unabated fossil-fuel development.

The burden is highly concentrated in the agriculture sector, which accounts for 1.36 million FTE annual job losses in SSP1-2.6, rising to 2.16-2.32 in the high-emissions scenarios (SSP3-7.0 and SSP5-8.5), about 10% 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 320-564 thousand FTEs (3-5% of sector total) across the scenario range, given that much of Ethiopia's retail, hospitality, and informal urban commerce occurs in environments with limited climate control. Construction follows with 42-75 thousand annual FTE job losses (5-10% of sector total), suggesting that existing regulations and cooling measures in construction sites and infrastructure projects remain insufficient to offset rising WBGT. Annual losses in manufacturing (29 to 51 thousand FTEs; 2-4% of sector total) as well as transport and trade (20 to 34 thousand FTEs; 3-6% of sector total) are smaller in absolute terms but remain proportionately significant given those sectors' smaller employment base. Mining and quarrying show smaller impacts (7 to 13 thousand FTEs; 4-6% of sector total), underscoring the advantage of mechanisation and limited workforce size.

Table 6 shows the annual projected labour market impacts of rising heat stress due to climate change during 2060 in each sector of economic activity 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 2.13-5.97 million FTE jobs from Ethiopia's economy each year, depending on the global emissions pathway. Estimates show that under the Paris-consistent trajectory (SSP1-2.6) Ethiopia will annually lose 2.13 million FTEs, or about 5.9% of total labour force. The toll rises sharply to 3.99 million FTEs under SSP2-4.5, 5.01 million under SSP5-8.5, and peaks at nearly 6 million under SSP3-7.0, where heat cuts 16.6% 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 1.65 million FTEs in the low-emissions scenario, climbing to 4-4.6 million FTEs in the two high-emissions scenarios, about 18-21% of the sector's labour force. Services, often characterised by environments with limited climate control, ranks second, with losses escalating from 363 thousand to over 1 million FTEs across the scenario range. Construction shows comparable patterns (49-141 thousand FTEs). Manufacturing, where small workshops often lack adequate cooling, will lose 32-92 thousand FTEs, while transport and trade are expected to record up to 64 thousand FTE losses. Finally, FTE losses in mining and quarrying will range from 8.5 to 23.9 thousand, a smaller impact owing to mechanisation and limited labour market size. Therefore, implementation of climate mitigation and adaptation policies will save more than 2.25 million FTE jobs per year in agriculture, 0.5 million FTE jobs in services, as well as about 170,000 FTE jobs in the other industrial sectors (Infographic 3).

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	44,221,792,011	-2,737,163,982	-6.19	-1,364,489
	SSP2-4.5		-3,783,963,741	-8.56	-1,886,323
	SSP3-7.0		-4,657,984,039	-10.53	-2,322,026
	SSP5-8.5		-4,325,196,653	-9.78	-2,156,130
Construction	SSP1-2.6	1,557,148,320	-83,671,897	-5.37	-41,711
	SSP2-4.5		-117,648,271	-7.56	-58,648
	SSP3-7.0		-151,031,166	-9.70	-75,290
	SSP5-8.5		-127,909,572	-8.21	-63,763
Manufacturing	SSP1-2.6	2,455,230,960	-57,452,429	-2.34	-28,640
	SSP2-4.5		-77,240,481	-3.15	-38,505
	SSP3-7.0		-101,399,925	-4.13	-50,548
	SSP5-8.5		-90,260,924	-3.68	-44,995
Mining and Quarrying	SSP1-2.6	399,068,949	-14,293,947	-3.58	-7,126
	SSP2-4.5		-18,966,183	-4.75	-9,455
	SSP3-7.0		-25,665,153	-6.43	-12,794
	SSP5-8.5		-21,326,181	-5.34	-10,631
Services	SSP1-2.6	22,176,839,880	-643,501,996	-2.90	-320,789
	SSP2-4.5		-864,418,302	-3.90	-430,916
	SSP3-7.0		-1,132,037,992	-5.10	-564,326
	SSP5-8.5		-932,427,674	-4.20	-464,819
Transport and Trade	SSP1-2.6	1,197,630,051	-39,943,275	-3.34	-19,912
	SSP2-4.5		-53,751,554	-4.49	-26,795
	SSP3-7.0		-68,968,769	-5.76	-34,381
	SSP5-8.5		-61,265,492	-5.12	-30,541
TOTAL	SSP1-2.6	72,007,710,171	-3,576,027,525	-4.97	-1,782,666
	SSP2-4.5		-4,915,988,532	-6.83	-2,450,642
	SSP3-7.0		-6,137,087,044	-8.52	-3,059,365
	SSP5-8.5		-5,558,386,496	-7.72	-2,770,881

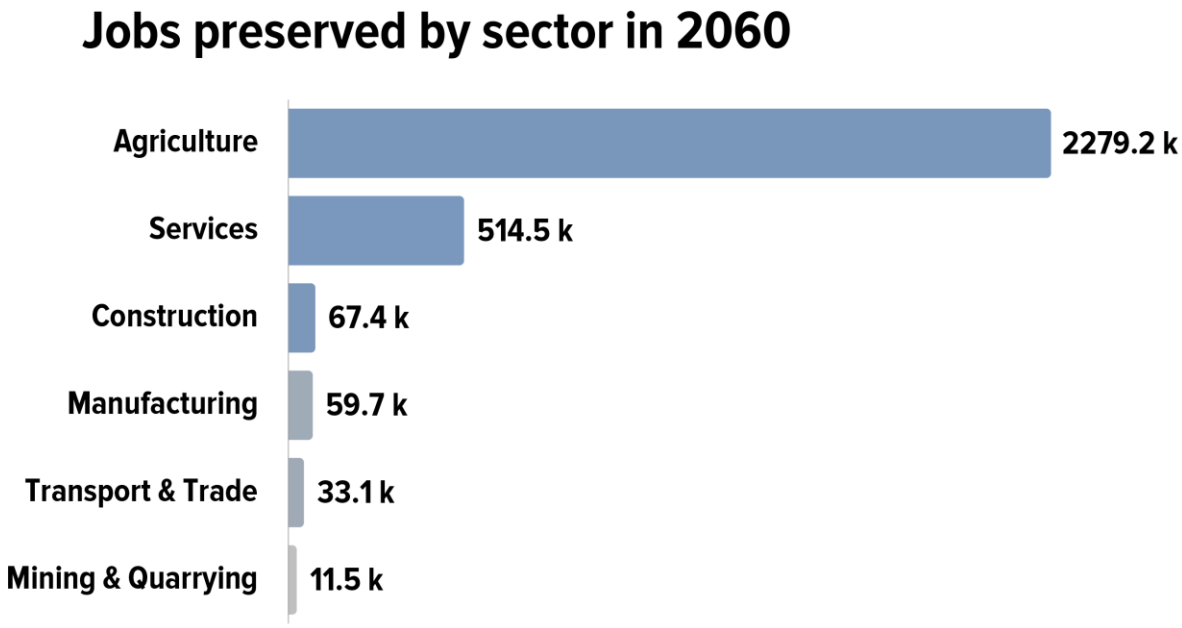
SSP: shared socioeconomic pathway; n: number; FTE: full-time equivalent.

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	44,221,792,011	-3,310,220,894	-7.49	-1,650,160
	SSP2-4.5		-6,178,992,194	-13.97	-3,080,255
	SSP3-7.0		-9,284,958,450	-21.00	-4,628,593
	SSP5-8.5		-7,882,285,429	-17.82	-3,929,355
Construction	SSP1-2.6	1,557,148,320	-98,201,916	-6.31	-48,954
	SSP2-4.5		-191,069,519	-12.27	-95,249
	SSP3-7.0		-283,336,103	-18.20	-141,244
	SSP5-8.5		-233,497,600	-15.00	-116,400
Manufacturing	SSP1-2.6	2,455,230,960	-63,940,981	-2.60	-31,875
	SSP2-4.5		-128,341,292	-5.23	-63,979
	SSP3-7.0		-185,132,286	-7.54	-92,289
	SSP5-8.5		-183,664,221	-7.48	-91,557
Mining and Quarrying	SSP1-2.6	399,068,949	-17,196,053	-4.31	-8,572
	SSP2-4.5		-32,382,535	-8.11	-16,143
	SSP3-7.0		-47,966,137	-12.02	-23,911
	SSP5-8.5		-40,196,506	-10.07	-20,038
Services	SSP1-2.6	22,176,839,880	-727,801,740	-3.28	-362,812
	SSP2-4.5		-1,378,567,439	-6.22	-687,222
	SSP3-7.0		-2,040,521,610	-9.20	-1,017,209
	SSP5-8.5		-1,759,842,749	-7.94	-877,290
Transport and Trade	SSP1-2.6	1,197,630,051	-46,379,186	-3.87	-23,120
	SSP2-4.5		-87,292,351	-7.29	-43,516
	SSP3-7.0		-129,226,197	-10.79	-64,420
	SSP5-8.5		-112,778,954	-9.42	-56,221
TOTAL	SSP1-2.6	72,007,710,171	-4,263,740,770	-5.92	-2,125,494
	SSP2-4.5		-7,996,645,330	-11.11	-3,986,364
	SSP3-7.0		-11,971,140,783	-16.62	-5,967,667
	SSP5-8.5		-10,212,265,460	-14.18	-5,090,860

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

Infographic 3. Sectoral labour market benefits of implementing in Ethiopia 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 nearly 3 million 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 Ethiopia'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 Ethiopia

Ethiopia 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 Ethiopia 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, Ethiopia has ratified 23 ILO conventions, including 9 of the 10 fundamental ones.[55] Also, some key OSH conventions relevant to managing heat stress have been ratified by Ethiopia. These include Convention No. 155 (Occupational Safety and Health [OSH]), which mandates the establishment of policies to prevent occupational accidents and illnesses. However, other OSH conventions that are critical for managing workplace heat stress have not been ratified by Ethiopia. These include:

- **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 Ethiopia'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 Ethiopia'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 Ethiopia'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 Ethiopia'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 Ethiopia 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 Ethiopia's broader climate and development objectives. Integrating OSH standards into climate adaptation efforts supports Ethiopia'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.

[55] https://normlex.ilo.org/dyn/nrmlx_en/f?p=1000:11200:0::NO:11200:P11200_COUNTRY_ID:102950

6.2. Policy recommendations for climate adaptation

In a Consultation Meeting carried out as part of the development of this study, local stakeholders recognised workplace heat stress as an emerging occupational and public health concern, particularly in agriculture, construction, and horticulture. Given that approximately two-thirds of Ethiopia's workforce is employed in agriculture, the meeting participants stressed the need for comprehensive, regionally differentiated assessments and tailored sector-specific interventions. The local stakeholders also noted significant constraints related to human capital and institutional capacity, including low awareness of workplace heat stress and weak OSH culture, sector-wide skills gaps, high turnover of government personnel and OSH focal points, regional disparities in institutional capacity and resources, inconsistent integration of climate considerations into OSH planning, as well as limited advocacy and public engagement on occupational risks related to climate change. Additional constraints included limited financial resources for OSH implementation, restricted access to appropriate technologies for monitoring and mitigation, and resistance from some employers to investing in OSH measures related to workplace heat stress. In light of these challenges, to enhance Ethiopia'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:** In a Consultation Meeting carried out as part of the development of this study, local stakeholders noted weak enforcement of existing OSH regulations, insufficient and fragmented data and information systems, and the need to shift from voluntary corporate social responsibility approaches toward enforceable corporate accountability mechanisms for worker protection. To reverse this situation, Ethiopia 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. 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:** Ethiopia 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:** In a Consultation Meeting carried out as part of the development of this study, local stakeholders noted institutional fragmentation and weak coordination among relevant ministries and agencies were identified as major barriers. In addition, limited tripartite dialogue and weak negotiation mechanisms constrain effective collaboration between government, employers, and workers. To reverse this situation, employers in Ethiopia 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 Ethiopia's agriculture and construction sectors, where exposure to high heat exposure is frequent.

4. **Integration of Heat Stress into National OSH Policies:** In a Consultation Meeting carried out as part of the development of this study, local stakeholders noted that Ethiopia's current National OSH Policy and Strategy do not explicitly recognise workplace heat stress as a physical hazard. At the same meeting, participants highlighted institutional fragmentation, weak tripartite mechanisms, limited social protection coverage, financial constraints, technological gaps, and employer resistance as persistent structural barriers requiring coordinated policy responses. To reverse this situation, Ethiopia 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]

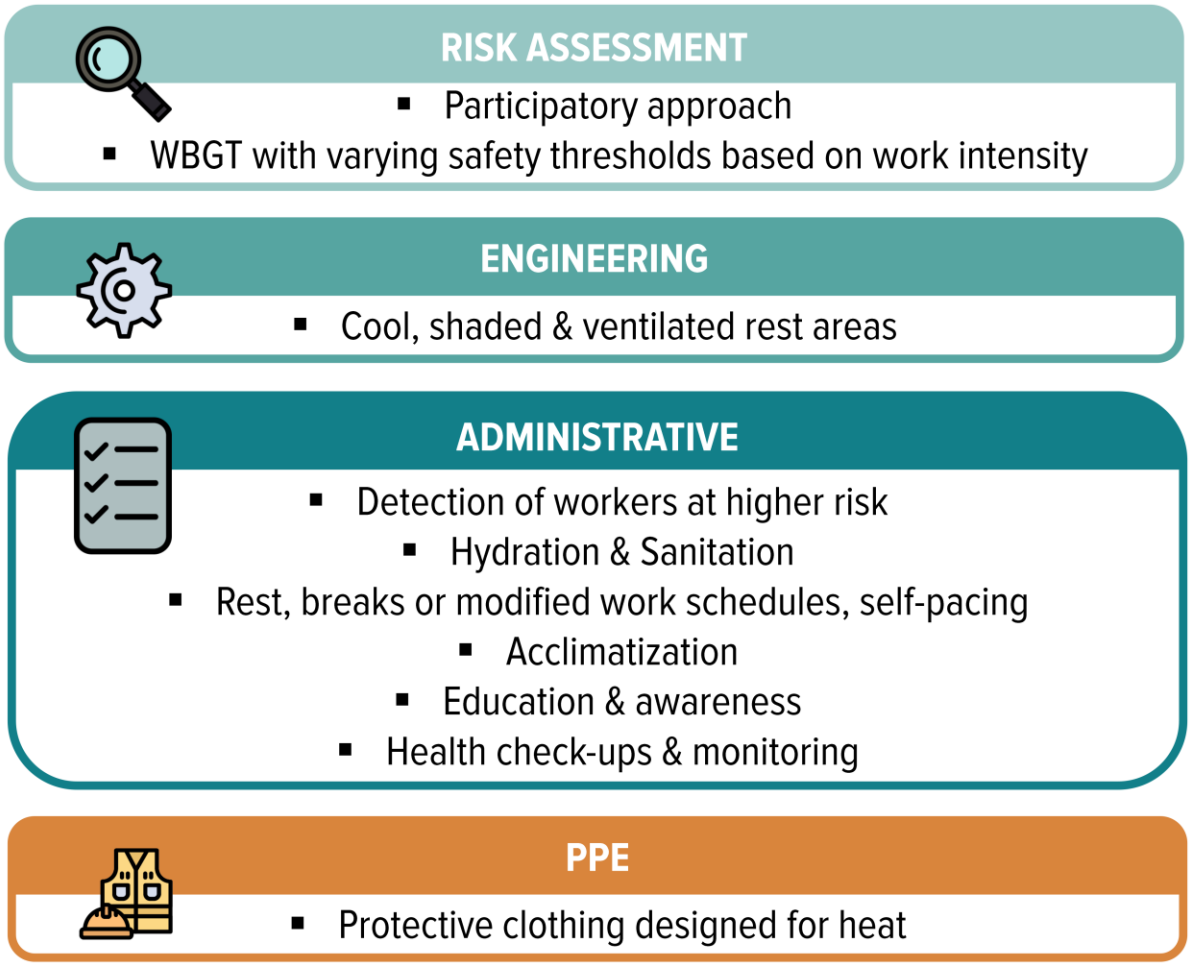
   Targeted awareness-raising and training programmes should be developed for policymakers, government institutions, employers, workers, and other stakeholders to address widespread knowledge gaps related to climate change and workplace heat stress. A comprehensive national workplace heat stress mitigation plan should be developed and implemented through collaboration among government, employers, workers, and society at large. An inclusive mitigation strategy should be adopted, explicitly addressing gender, disability, and other vulnerability dimensions, supported by a clear and enforceable code of conduct. Research and development, together with continuous capacity-building and skills assessments, should be strengthened.

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 Ethiopia, particularly in sectors most vulnerable to heat stress. It is important that Ethiopia's health services should 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 incentivize 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, Ethiopia 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 Ethiopia'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 Ethiopia. In light of the evidence presented in this 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,

Ethiopia can protect its workforce, sustain productivity, and enhance the resilience of its economy in the face of a warming climate.

Agriculture: In agriculture, 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 Ethiopia, as demonstrated in this study. This agenda aims to provide safe, productive, and fair working conditions, which are increasingly critical as Ethiopia faces heightened climate impacts, particularly rising heat stress levels. By adopting these measures, Ethiopia 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 Ethiopia's labour market, aligning with both global labour standards and climate objectives.

- **Promoting Safe and Healthy Workplaces in Ethiopia Amidst Rising Heat:** The Decent Work Agenda[56] prioritizes safe and healthy workplaces as essential for sustainable and equitable employment. For Ethiopia, adopting OSH Conventions such as 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 Ethiopia'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.[57]

- **Enhancing Productivity through Climate-Responsive OSH Measures:** Safe working conditions are essential to sustaining worker productivity, a core priority of the Decent Work Agenda.[57] Implementing heat adaptation strategies, such as structured work-rest cycles and hydration protocols, allows Ethiopia 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.[57]

- **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.[57] Applying OSH standards to address climate risks helps prevent these workers from being disproportionately affected by rising heat. By mandating workplace safety measures, Ethiopia 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.[57] By adopting ILO OSH Conventions, Ethiopia 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.[57]

[56] 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).

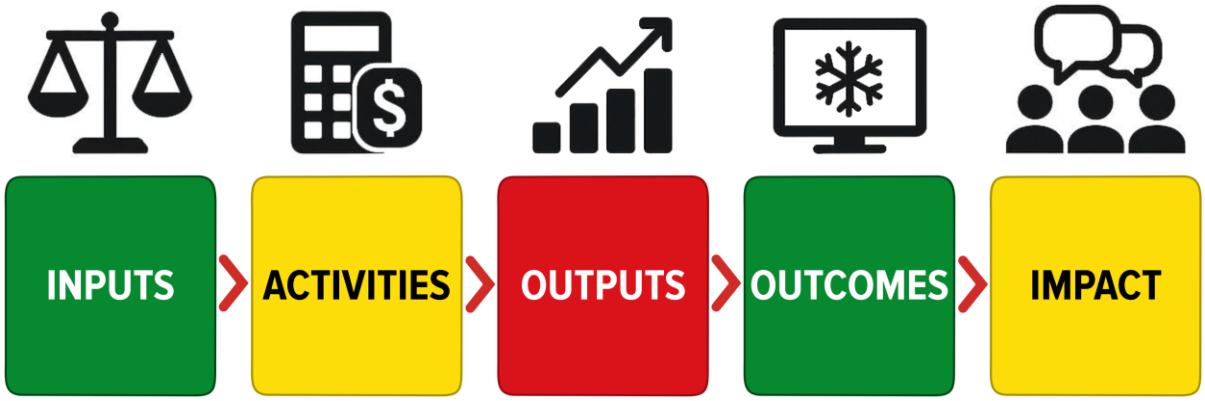
- **Contributing to Ethiopia's Just Transition to a Climate-Resilient Economy:** Incorporating the Decent Work Agenda into climate adaptation initiatives also aligns with Convention No. 187 (Promotional Framework for OSH), which encourages continuous improvement in national OSH policies. This framework is key to Ethiopia's just transition, supporting the development of a climate-resilient economy by fostering equitable and sustainable working conditions across all sectors. By embedding OSH standards within climate policies, Ethiopia 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 Ethiopia. This will ensure that these policies will 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 Ethiopia, 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 Ethiopia 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 analysis was used to examine how full implementation of the ILO Decent Work Agenda and the 2030 Agenda for Sustainable Development could change Ethiopia's economic and labour-market trajectory under rising workplace heat stress. The analysis 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). The analysis contrasts the two policy futures (SSP1-2.6 vs. SSP5-8.5) and explains how full implementation of the ILO Decent Work Agenda and the 2030 Agenda can change Ethiopia's economic and labour-market trajectory under rising workplace heat stress (concept outlined in Infographic 5).

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



Inputs are political commitment to the four pillars of Decent Work (employment, rights, social protection, social dialogue); budgetary allocations and climate-finance inflows; and ILO 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 comprise: (1) ratification and enforcement of ILO Conventions 161 and 187; (2) a national heat-stress code of practice anchored in the 10 ILO protection requirements and the recommendations of Section 6 above – the main pillar here is adopting and enforcing a national heat-stress standard based on WBGT with work-rest schedules, hydration, shade/ventilation, and acclimatisation provisions; (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; (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 are the rapid scaling of heat-safe worksites, increased coverage of social insurance, and active programmes for green and resilience-oriented employment.

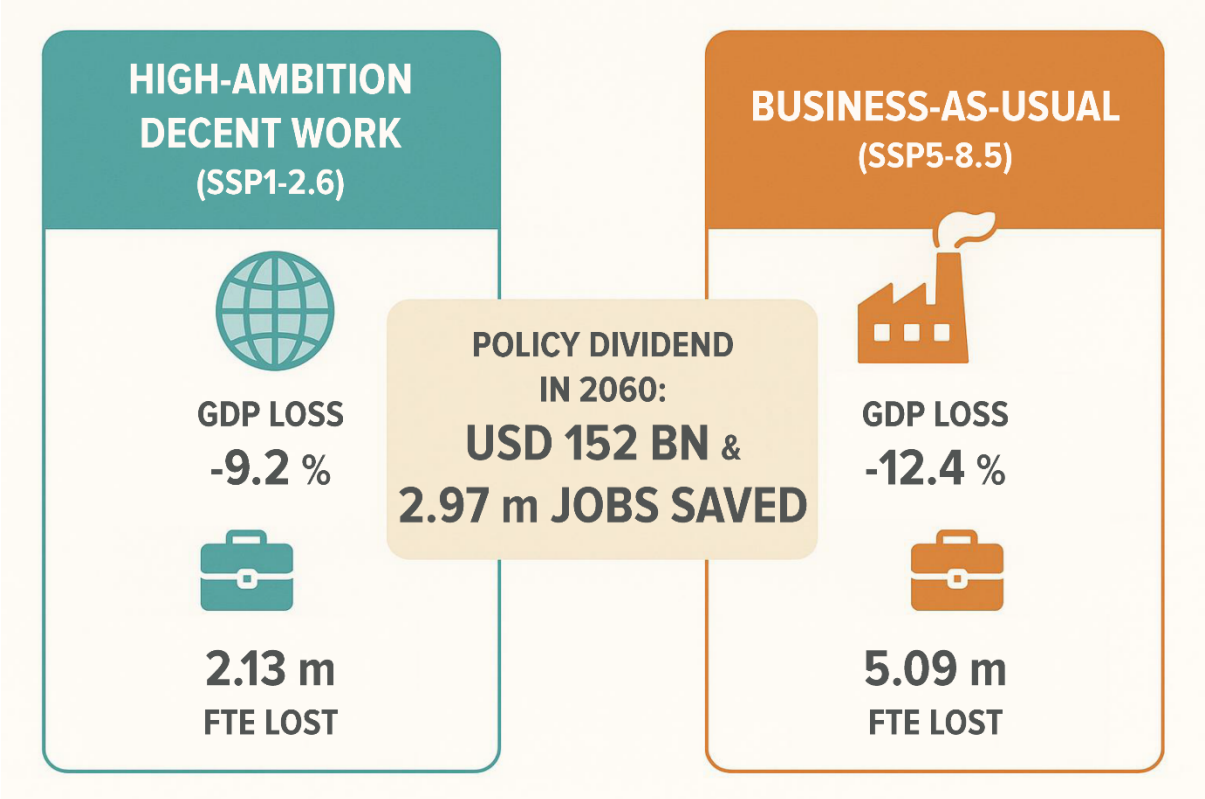
Outcomes include lower heat-related work-time loss, reduced injuries and absenteeism, improved retention and productivity (especially for women and youth concentrated in agriculture, services, and manufacturing) and higher resilience among informal and rural workers.

The long-term ***impact*** is higher effective labour supply, safeguarded GDP, and progress towards SDG 8 (decent work and economic growth), SDG 3 (health and well-being), and SDG 13 (climate action), with co-benefits for poverty reduction and gender equality. Key results are summarized in Infographics 6-7.

- **Scenario A: High-Ambition Decent Work (Decent Work + SDGs implemented; climate consistent with SSP1-2.6).** Global mitigation follows SSP1-2.6. Without additional measures, Section 5 projects annual GDP losses of **33.3 billion USD** in 2040 and **158.4 billion USD** in 2060 compared with the 1985-2014 baseline. The corresponding losses in FTE jobs are **1.8 million** in 2040 and **2.1 million** in 2060. Under this scenario, Ethiopia implements the Decent Work package at scale, particularly in relation to workplace heat stress. In short, this "high-action" scenario portrays an Ethiopia that achieves **resilient growth** – protecting workers from climate hazards, creating new decent jobs in sustainable industries, and, thus, advancing multiple SDGs (decent work, poverty reduction, good health, climate action). It exemplifies how implementing the Decent Work Agenda and 2030 Agenda **reduces vulnerabilities and strengthens the economy** in the face of climate change.

- **Scenario B: Business-as-Usual (fragmented uptake; climate consistent with SSP5-8.5).** Global emissions track SSP5-8.5 and national uptake of Decent Work measures is piecemeal. Section 5 projects much heavier losses than those in Scenario A. Annual GDP falls by **48.2 billion USD** in 2040 and by **310.3 billion USD** in 2060 relative to the 1985-2014 baseline. Job-equivalent losses reach **2.8 million** FTE in 2040 and **5.1 million** in 2060. Health burdens rise and productivity falls, especially among outdoor and informal workers without access to cooling or paid leave.

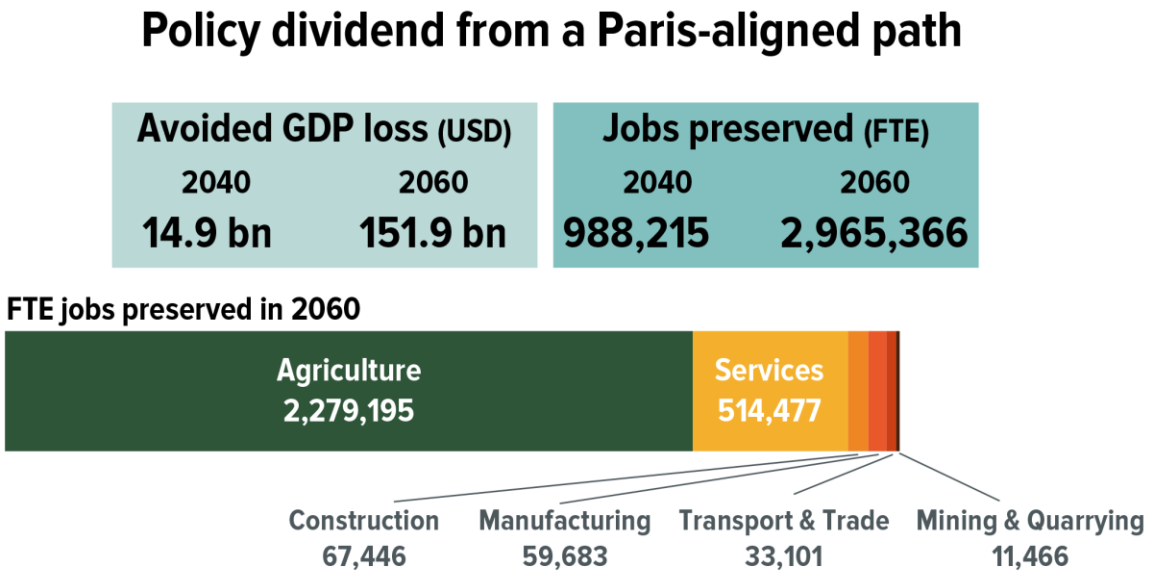
Infographic 6. Scenario analysis to decent work and sustainable development goal implementation in Ethiopia in relation to workplace heat stress. Figures calculated as differences between SSP5-8.5 and SSP1-2.6 based on the results presented in Section 5.



The policy dividend

Comparing the two scenarios shows the dividends from full Decent Work implementation in a low-emissions world. By 2040, avoided GDP losses are about **14.9 billion USD** each year and around **1 million FTE jobs** are preserved. By 2060 the annual GDP benefit rises to roughly **152 billion USD** and about **3 million FTE jobs** are preserved (Infographic 7). **Agriculture** and **services** capture the largest share of these benefits because they account for the bulk of current and projected losses. In 2023 alone, heat stress already cut GDP by an extra 8 billion USD relative to the historical period. Agriculture accounted for 3.1 billion USD of that total, services for 2.2 billion USD, and construction for 1.8 billion USD. These losses compound over time through lower productivity and industrial competitiveness, and limited worker retention.

Infographic 7. GDP and labour market benefits of implementing the decent work and sustainable development goals in Ethiopia, 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 effects

Beyond economic and employment aggregates, Decent Work implementation changes the *quality* and *distribution* of outcomes:

- **Productivity and business continuity:** These improve when companies adopt WBGT-based work-rest schedules, provide shade and hydration, and install efficient cooling and ventilation. In retail, hospitality and small manufacturing, these steps reduce mid-day slowdowns and errors. In agriculture, construction and logistics, earlier starts, staggered shifts and evidence-based breaks keep output moving during peak heat.

- **Health and OSH outcomes:** Fewer cases of heat exhaustion, dehydration, and cardiovascular stress mean lower absenteeism and safer worksites. Occupational health services provide screening, hydration plans, and first aid, and support workers who need graded acclimatisation after absence.

- **Equity and informality:** Extending social protection floors to cover heat contingencies protects low-income workers, women, and migrants who are over-represented in outdoor services and agriculture. Income protection during heat alerts prevents negative coping strategies and helps keep children in school. Enforcement of minimum heat-safety standards in informal settings reduces the gap between formal and informal work.

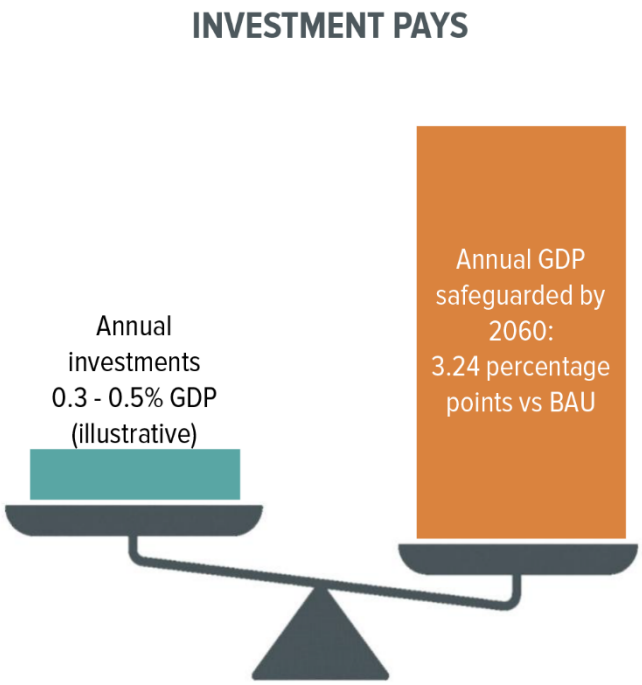
- **Skills and just transition:** Training in heat-safe work methods, maintenance of efficient cooling, and climate-smart agriculture grows new jobs while upgrading existing ones. This supports a just transition that protects workers as the climate warms.

- **Governance and dialogue:** Tripartite dialogue helps tailor sector protocols, align incentives, and avoid wage penalties when breaks are extended. Labour inspection, public procurement, and city-level planning anchor compliance and scale.

Implementation priorities

Workplace heat stress represents a significant and growing occupational, economic, and social challenge for Ethiopia. Given the country's predominantly agrarian labour force and expanding heat-exposed sectors such as horticulture and construction, the implications for livelihoods and productivity are substantial. To realise Scenario A, three enablers are pivotal. First, embed **WBGT-based heat standards** in OSH regulation and public procurement and support them with labour inspection and worker participation. Second, extend **social protection floors** to cover heat-related sickness and income loss with simple triggers and rapid payment. Third, direct at least **0.3-0.5% of GDP per year in public and concessional finance to efficient cooling** in SMEs and public facilities, urban heat mitigation, shaded transport hubs 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. **Progress should be tracked** against the Section 5 baselines using three simple metrics: GDP safeguarded each year, FTE jobs preserved each year, and days above critical WBGT thresholds avoided. Additional activities are provided in Infographic 6.

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).



The contrast between the two futures is stark. A high-ambition Decent Work and SDG pathway preserves output, protects workers and sustains inclusion. A business-as-usual path erodes labour capacity and compresses growth. Ethiopia can reduce the macro-economic burden of heat by combining international mitigation with a domestic Decent Work package centred on OSH, social protection, green investment and social dialogue.

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 Ethiopia'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 Ethiopia'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.[52] This function was derived from field studies across various countries and is calibrated for an "average, experienced, acclimatized worker" operating under typical conditions.[52] While this provides a robust general framework, it may not capture all nuances of Ethiopian labour contexts. For instance, actual work-rest behaviours, acclimatization levels, and protective measures in Ethiopia 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.[36] 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 Ethiopia. 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**. Ethiopia's complex terrain and microclimates – from cooler higher altitude areas to hotter, humid lowland 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 Ethiopia'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 this 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 Ethiopia. In reality, Ethiopia's future emissions and development path may not neatly correspond to any single SSP. Ethiopia'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 Ethiopia. By using one model, the analysis assumes its simulation is representative, but if that

model underestimates (or overestimates) future heat extremes in Ethiopia, 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 Ethiopia 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 Ethiopian 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 Ethiopia'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, Ethiopian 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 current 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 Ethiopian 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 Ethiopia 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 an Ethiopian 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 lowland 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 Ethiopia 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 Ethiopia'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 this study properly account for its scope and the uncertainties in projecting climate change impacts on Ethiopia'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[57] was adopted because it is considered the most accurate method when calculating WBGT from meteorological data.[58] 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.[59] Solar radiation was estimated[60] 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.[61] 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.[59] Indoor temperature and humidity were estimated as a function of outdoor conditions.[62] Similarly, for the mining industry, underground temperature[63] and humidity[64] 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,[65] 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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[65] Center for International Earth Science Information Network - CIESIN - Columbia University, Gridded Population of the World, Version 4 (GPWv4): Population Count, Revision 11. 2018, NASA Socioeconomic Data and Applications Center (SEDAC): Palisades, New York.

Population projections datasets, based on the SSP1, SSP2, SSP3, SSP4, and SSP5 were obtained from standard sources.[66,67] 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.[68] 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[69] 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,[70] 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.[71,72,73] 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.[74] 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)[75] 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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[71] Karger D.N., Conrad O., Böhner J., Kawohl T., Kreft H., Soria-Auza R.W., Zimmermann N.E., Linder H.P., Kessler M. (2017). Climatologies at high resolution for the earth's land surface areas. Scientific Data; 4: 170122.
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the urban area cells using xarray's coarsen method.[76] 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[77] 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.[78] 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,[79] 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.[80]

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).[81] The conversion was performed as follows: GDP_MER=GDP_PPP*PLR

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

A1.2.8. Employment Dataset

Economic activity data was obtained from ILOSTAT,[82] 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[83] 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.[84] 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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