International Labour Organization

Impacts of heat stress on jobs and productivity in Lebanon

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



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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, 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 Lebanon'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. ILO in Lebanon

Lebanon is currently facing significant socio-economic challenges, exacerbated by ongoing political and security instability and a deepening economic crisis. Since 2022, the country has been governed by a caretaker government, unable to advance critical reforms that could mitigate the rise in poverty and vulnerability. This political deadlock, alongside economic stagnation, has resulted in a continuous increase in unemployment and underemployment, particularly among vulnerable groups such as women and youth.

In this context, addressing the labour market implications of climate policies—such as those aimed at reducing heat stress in workplaces—becomes even more urgent. The lack of economic resilience in Lebanon complicates the task of ensuring a just transition that safeguards the rights and livelihoods of workers, particularly those in sectors such as agriculture and construction, where exposure to heat stress is high.

[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.

Despite Lebanon's enduring political and economic challenges, the ILO has been actively involved in supporting the Government in addressing labour market and decent work challenges and opportunities. Lebanon has ratified 51 ILO Conventions, including 7 of the 10 fundamental ones that cover human rights at work. In collaboration with national stakeholders, the ILO has prioritized creating decent work opportunities through its Decent Work Country Programme, focusing on improving governance, legislative frameworks, and labour market conditions. The ILO also plays a crucial role in addressing informal employment, which has increased sharply, with over 48% of the workforce engaged in informal jobs.

The ILO's initiatives in Lebanon span multiple sectors, from supporting Syrian refugees and Lebanese host communities through skill-building programmes, to efforts in labour inspection and social protection system reforms. The organization has been working with the Lebanese Ministry of Labour on restructuring policies and improving labour inspection systems to safeguard workers' rights.

A previous report on Lebanon's labour inspection system, conducted under the auspices of the ILO, provides a thorough evaluation of Lebanon's labour inspection framework, highlighting the strengths and weaknesses in its legal and organizational structure, as well as its human resource and logistical capacities.[2] It underscores gaps in OSH legislation, insufficient training and staffing for inspectors, and inadequate mechanisms for documenting occupational injuries and diseases. These limitations, combined with a focus on machinery licensing instead of broader workplace hazards, reflect the need for a more cohesive national OSH strategy and an expansion of inspection activities beyond the small percentage of enterprises currently monitored. Although the previous ILO report comprehensively examines the relevant legislative and policy landscape, there is no mention of heat stress as there is no specific legislation or framework to address this hazard in Lebanon.

Given Lebanon's ongoing socio-economic crisis, it is crucial that the climate and environment policies to be designed are in line with the ILO Guidelines for a just transition towards environmentally sustainable economies and societies for all, ensuring that policies maximize the opportunities and minimize any challenges from the transition, including for workers in heat sensitive sectors. Coordinated efforts between the Government of Lebanon, international organizations, and civil society are essential to ensuring that climate actions promote economic recovery and safeguard employment.

[2] ILO (2009). Lebanon labour inspection audit. Joint outcome on labour inspection. Labour Administration and Inspection Programme. International Labour Office. Geneva, Switzerland.

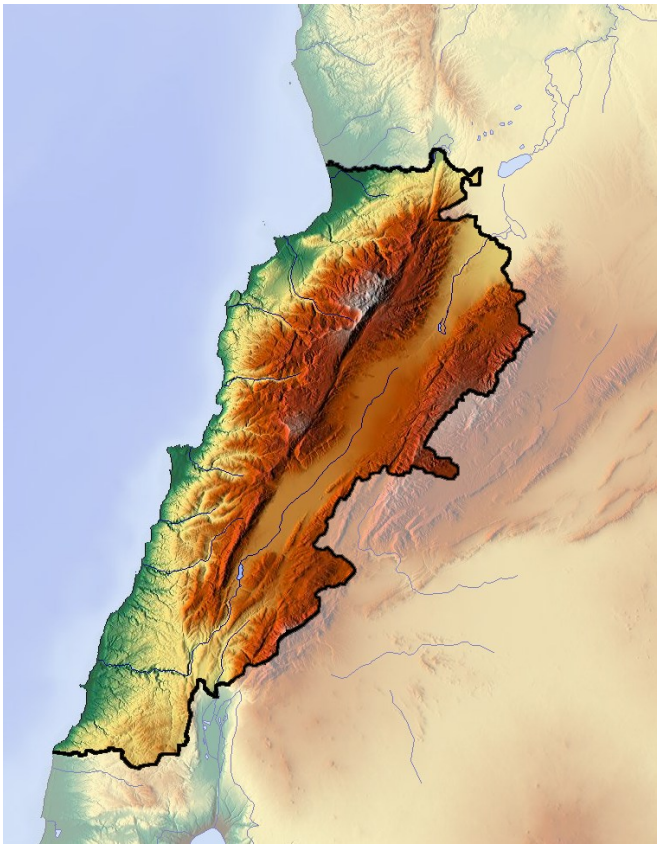
2. Current and future heat exposure and climate change

2.1. Current weather and climate overview

Lebanon is at the crossroads of the Mediterranean Basin and the Arabian Peninsula (Figure 1). Its climate is typical of the Mediterranean region, characterized by hot, dry summers and cool, wet winters. Along the coastal areas, average summer temperatures frequently exceed 35°C, while inland areas experience more extreme temperature variations due to the lack of the sea's moderating influence. Winters along the coast are milder, with average temperatures between 5°C and 10°C, while mountainous regions receive significant snowfall during the colder months.

Annual precipitation is unevenly distributed, with the majority falling between November and March, primarily in heavy bursts of rain or storms. Coastal areas typically see between 700 and 1,000 mm of rain annually, while mountainous regions see higher totals, reaching up to 1,600 mm. However, the intensity and irregular distribution of rainfall exacerbate issues like water scarcity, as much of it is lost as runoff during short, heavy rainfall events.

Figure 1. Lebanon physical map.[3]



2.2. Choice of environmental indicators

To characterize the prevailing environmental conditions for work in Lebanon, 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.[4]

Wet-Bulb Globe Temperature (WBGT): The WBGT is the most widely adopted indicator by scientists and occupational health and safety professionals

[3] The map was made using http://www.maps-for-free.com

[4] 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.

to assess heat stress in the workplace and its effects on health and productivity.[4,5,6,7] 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.[4,8,9,10] 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.[1,11] 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.[12]
- **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.[13]
- **Fatigue and cognitive impairment:** Higher WBGT levels are associated with quicker onset of fatigue and reduced cognitive function, impacting decision-making and coordination.[1,14,15]
- **Heat-related illnesses:** Prolonged exposure can result in dehydration, heat cramps, heat exhaustion, or even heat stroke, especially in high-intensity work environments.[1,13] Working in a hot environment for a significant part of the year can lead to acute/chronic kidney injury.[1,13]

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

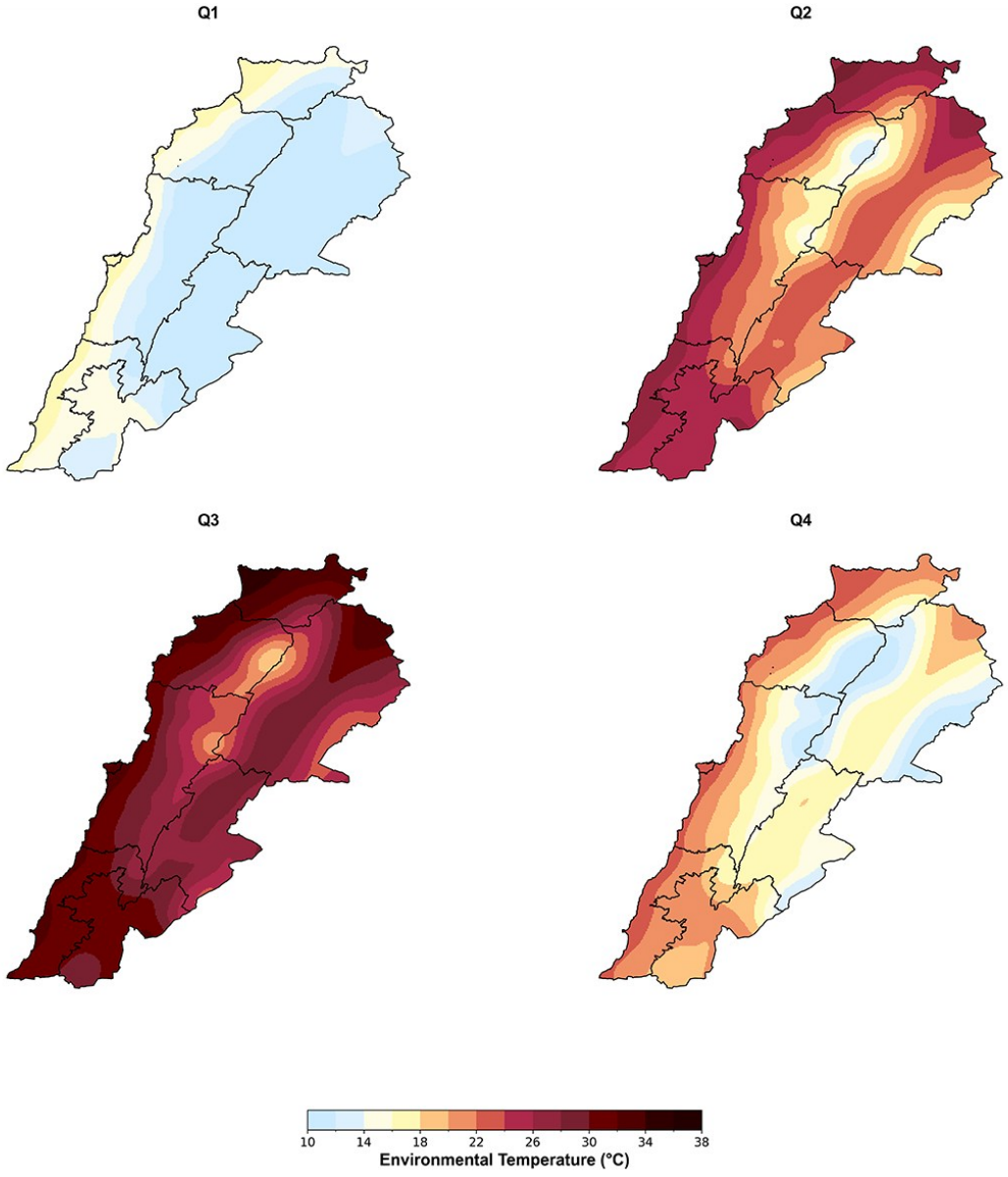
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[5] NIOSH, Criteria for a recommended standard: occupational exposure to heat and hot environments, B. Jacklitsch, et al., Editors. 2016, Centers for Disease Control and Prevention. National Institute for Occupational Safety and Health. U.S. Department of Health and Human Services: Cincinnati, OH, USA.
[6] 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.
[7] ACGIH, Heat stress, TLVs and BEIs: threshold limit values for chemical substances and physical agents & biological exposure indices, ACGIH, Editor. 2020, ACGIH: Cincinnati.
[8] 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.
[9] 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.
[10] 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.
[11] World Health Organization and World Meteorological Organization (2025). Climate change and workplace heat stress: technical report and guidance. Geneva, Switzerland.
[12] 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.
[13] 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.
[14] Flouris A.D. (2019). Human thermoregulation. in: Périard J., Racinais S., eds. Heat stress in sport and exercise: Springer.
[15] 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 Lebanon. The maps show a clear seasonal cycle with a strong geographic trend. The Mount Lebanon and Anti-Lebanon mountain range stay cooler year-round, while the coastal plain and the Bekaa Valley warm earliest and most. The north-south contrast is modest compared with the sharp coast-mountain-valley gradient.

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



Seasonality

- **Q1 (Jan-Mar)** is the coolest quarter nationwide. Most of the country sits in the cool range, with the Mount Lebanon range and high plateaus are markedly colder than the coast. Coastal cities are milder but still far from summer heat.
- **Q2 (Apr-Jun)** shows a rapid warm-up. Heat spreads inland from the coast and valleys. The Bekaa and leeward slopes warm strongly while the highest ridges remain noticeably cooler.

- **Q3 (Jul-Sep)** represents the peak heat period. Very high maxima dominate almost everywhere, especially in lowlands and valley floors where the maps show the darkest tones. Mountain areas are relatively cooler but still warm compared with earlier quarters.
- **Q4 (Oct-Dec)** shows a transition back to cooler conditions. A clear gradient appears: coastal belts and the far south remain warm late into the year, while interior highlands cool quickly.

Spatial patterns

- **Altitude impact:** A persistent temperature gradient follows topography. High elevations along the Mount Lebanon range are coolest in every quarter. Low coastal plains and interior valleys warm earliest in Q2 and stay hottest in Q3.
- **Valley amplification:** The Bekaa corridor stands out in Q2-Q3 as a hot strip compared with surrounding mountains, reflecting lower elevation, shelter from maritime cooling, and strong solar loading.
- **Coast-interior contrast:** The coast moderates winter cold in Q1 and retains warmth into Q4, while the interior cools faster in autumn.
- **Sharp local gradients:** Short distances separate very different conditions across slope aspects and elevations, implying micro-climates within districts.

Implications for labour and OSH planning

- **High-risk window by air temperature:** Plan for the greatest heat pressure in Q2-Q3, especially across coastal districts and the Bekaa where outdoor and high-exertion work is common. Plan earlier starts, extended midday breaks, task rotation, and access to shade and hydration during these quarters.
- **Regional targeting:** Prioritise heat-risk management along the Beirut-Jounieh-Saida coastal corridor, Tripoli and Tyre, and the Bekaa around Zahle, where peak maxima and worker concentrations overlap. Mountain communities face lower maxima but can still see strenuous tasks in strong sun; tailor controls to task intensity and exposure.
- **Q4 vigilance on the coast:** Maintain precautions for coastal worksites into autumn when temperatures remain elevated relative to the interior.
- **Urban micro-hotspots:** Anticipate higher local heat loads in dense urban areas due to the urban heat-island effect and low wind conditions. Incorporate cooling, ventilation, and shaded rest areas into construction sites, markets, transport hubs, and municipal works.

Overall, Lebanon's environmental temperature rises quickly in Q2 and peaks in Q3, with strong elevation and valley effects. These patterns support a practical calendar for heat-risk controls, with the most stringent measures in Q2-Q3 for coastal and valley workplaces and continued, lighter precautions on the coast in Q4.

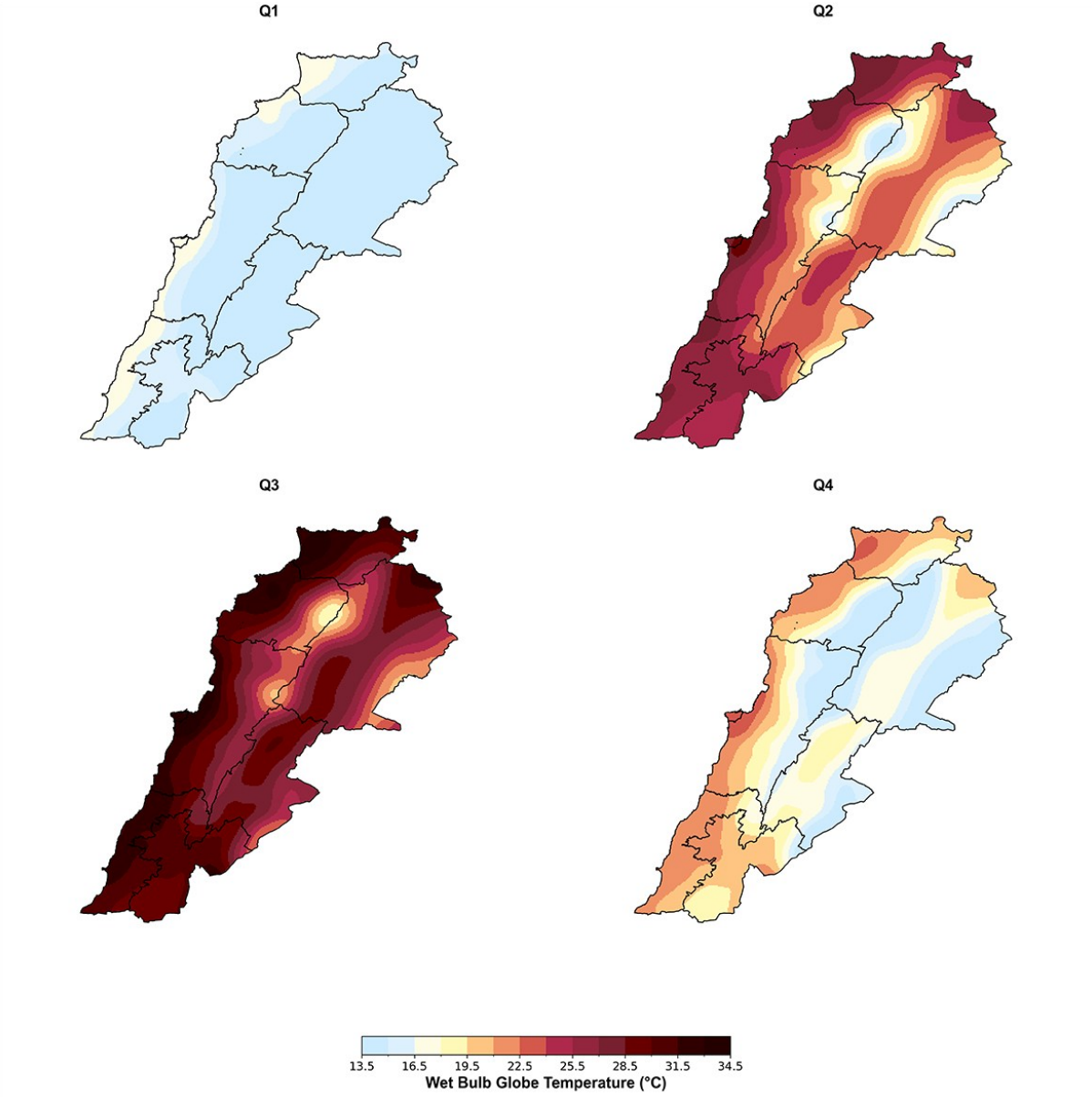
Figure 3 illustrates the quarterly average maximum WBGT across Lebanon. WBGT is an important measure of heat stress, taking into account not only temperature but also humidity, wind speed, and solar radiation, which makes it particularly useful in assessing the risk of heat stress for working people. The maps show a clear seasonal cycle and a strong elevation effect. WBGT combines heat, humidity, wind and sun, so it reflects the conditions that drive heat strain at work around midday.

Seasonality

- **Q1 (Jan-Mar)** is the coolest part of the year. Most areas sit in the 14-20°C WBGT range. Heat stress risk is generally low, with the coast slightly warmer than inland.
- **Q2 (Apr-Jun)** brings a rapid rise in heat levels. Much of the country moves into 25-31°C WBGT. This is the onset of the main heat-risk season, especially at lower elevations and in coastal regions.
- **Q3 (Jul-Sep)** is the peak heat season. Large areas reach very high values near 31-34.5°C. In these conditions, continuous moderate or heavy work is unsafe without strong controls such as water–rest–shade, task rotation, cooling or ventilation.

- **Q4 (Oct-Dec)** shows a marked decline in heat stress levels. WBGT falls back toward 14-23 °C, with the interior and highlands cooling first and the coast remaining warmer longest.

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



Spatial patterns

- A persistent west–east and elevation gradient is evident. The coastal plain and other low-lying areas record the highest WBGT, reflecting warmer, more humid conditions and lighter winds.
- The Mount Lebanon and Anti-Lebanon mountain ranges remain comparatively cooler across all quarters, especially in Q1 and Q4, due to altitude and stronger ventilation.
- The Bekaa Valley is generally cooler than the coast in Q1 and Q4, but joins the national rise in Q2 and Q3 when solar load is high and winds are lighter.
- During Q3, the elevation advantage narrows: heat stress becomes widespread across the whole country, with pockets of very high WBGT extending inland as well as along the coast.

Implications for labour and OSH planning

- The primary risk window is in Q2 and Q3, with Q3 the period of greatest concern for outdoor and high-exertion work.
- Coastal cities and lowlands should be treated as priority areas for heat-risk management, given consistently higher WBGT and large worker populations.
- Highland districts offer some seasonal relief, particularly in Q1 and Q4, but still require precautions in Q2-Q3.
- Air temperature maps show the seasonal envelope of heat, but workplace decisions should be triggered by WBGT thresholds, which capture also humidity, wind, and sun. Pair site-level WBGT monitoring with simple action plans: water-rest-shade, earlier starts and longer mid-day breaks, acclimatisation for new or returning workers, and medical response and monitoring protocols.
- Facilities with indoor heat sources or limited ventilation can face high WBGT even when air temperature seems moderate; on-site WBGT monitoring is recommended.

Overall, Lebanon's heat-stress risk for workers is low in Q1, rises sharply in late spring, peaks in summer across most regions, and eases in autumn. Coastal and other low-elevation areas face the highest and most persistent WBGT, while altitude moderates but does not eliminate summer risk. These patterns support targeted, quarter-specific heat-risk controls anchored in WBGT guidance.

2.3.1. Findings from comparing temperature against WBGT

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

Seasonal alignment and key differences

- **Strong shared seasonality:** Both sets show a cool Q1 (Jan-Mar), a sharp warming in Q2 (Apr-Jun), a peak in Q3 (Jul-Sep), and easing in Q4 (Oct-Dec). Temperature rises from roughly 10-18°C in Q1 to 30-38°C in Q3; WBGT from about 13.5-19.5°C in Q1 to 31-34.5°C in Q3.
- **Earlier WBGT risk trend in Q2:** In Q2, WBGT already reaches the high-risk threshold (30-32°C) across many lowlands and coastal areas, while temperature shows a more moderate warming. This indicates that humidity and radiation bring heat stress forward in the year for workers along the coast and in valleys.

Spatial patterns that are consistent across both indicators

- **Elevation relief:** The Mount Lebanon range is a consistent cool corridor in all quarters. Elevation reduces both temperature and WBGT, offering the clearest seasonal relief.
- **Hot lowlands and valleys:** Coastal plains and the Bekaa Valley appear as the hottest regions in Q2-Q3 on both map sets. In Q3, both metrics show a marked hotspot over the northern Bekaa/inner valleys, reflecting strong trapping of heat and radiation.
- **North–south coastal stripe:** Along the Beirut-Tripoli-Tyre coastal axis, WBGT shows a more continuous high-stress ribbon than temperature in Q2-Q3, highlighting the role of humid maritime air.

Where WBGT changes the risk picture relative to temperature

- **Coastal amplification:** Compared to temperature, WBGT elevates coastal risk in Q2 and Q4 because humidity stays high even when air temperatures are only moderate. Workers may experience unsafe heat earlier and later than temperature alone suggests.

- **Valley and basin effects:** In Q2-Q3, WBGT accentuates hot corridors through the Bekaa and interior basins, where lighter winds and strong sun drive heat load above what air temperature alone implies.
- **Stronger north-south continuity of risk:** WBGT maps show fewer "cool spots" along the coast and lowlands than the temperature maps, meaning more widespread effects, particularly in outdoor work during Q2-Q3.

Implications for labour and OSH planning

- **Use WBGT, not air temperature, to trigger protections:** Set work-rest schedules, hydration plans, shade/ventilation, and acclimatization based on WBGT thresholds. In Q2-Q3 many lowland and coastal sites approach 30-34°C WBGT, where continuous moderate/heavy work is unsafe without strong controls.
- **Timing of measures:** In Q2, initiate heat-management protocols on the coast and in the Bekaa valley as WBGT risks arrive earlier than temperature alone suggests. In Q3, expand maximum protections nationwide, with special focus on lowlands, coast, and valleys. During Q4, keep coastal measures in place longer due to persistent WBGT, even as temperatures drop.
- **Targeted geography:** High-priority zones include Beirut and major coastal cities, the Bekaa Valley, and other low-elevation basins. Relative relief zones include higher-elevation communities along the Mount Lebanon range, though site-level checks remain necessary on sunny, no-wind days.
- **Urban considerations:** Expect urban heat-island effects to further raise WBGT in dense districts of Beirut and Tripoli, resulting in narrower safe work windows during Q2-Q3.

Overall, air temperature captures the broad seasonal cycle, but WBGT reveals when and where workers' heat strain actually peaks. For Lebanon, WBGT shows an earlier onset in Q2, a broad, intense peak in Q3 across lowlands and valleys, and slower coastal relief in Q4. Workplace planning and enforcement should therefore adjust decisions on WBGT, especially for outdoor and high-exertion tasks in coastal zones and the Bekaa valley.

2.4. Climate projections

2.4.1. Country overview

Lebanon's topography, which includes coastal plains, mountains, and valleys, plays a crucial role in shaping its climate patterns, but also contributes to its vulnerability to climate change. The projections from reports of the Intergovernmental Panel on Climate Change (IPCC)[16] for the eastern Mediterranean region indicate rising temperatures, more frequent and intense extreme weather events such as heatwaves and floods, as well as more irregular rainfall patterns. Given Lebanon's dependency on agricultural production, including sectors like wine, fruits, vegetables, and livestock, the projected shifts in temperature and precipitation patterns are likely to disrupt key economic activities. Also, the projected changes in climate will have significant implications for water resources, further straining the country's already fragile infrastructure and ecosystems.

Lebanon is a highly urbanized, middle-income country with a thriving tourism industry. Tourism contributes 20% to the country's Gross Domestic Product (GDP) and is highly weather dependent and vulnerable to higher temperatures.[17] Climate change, manifested through increasing temperatures, more frequent extreme weather events, and rising sea levels is expected to impact the densely populated coastal urban areas that host infrastructure and industry critical to the economy. Over 85% of Lebanon's residents live in urban areas concentrated along a coastline that is vulnerable to sea level rise.[17]

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[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] Credit Agricole Group (2024). Lebanon: economic and political overview. https://international.groupecreditagricole.com/en/international-support/lebanon/economic-overview

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.

2.4.2. Future climate change scenarios

To understand how future heat conditions might affect work in Lebanon, the present study uses four "storylines" known as Shared Socioeconomic Pathways (SSPs). These scenarios were used by the IPCC Sixth Assessment Report[16] 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,[16] 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.

It is important to note that there are several other SSPs and radiative forcing combinations available.[16] However, the present study focuses only on these four scenarios because they represent a wide range of potential futures – from a highly sustainable pathway to one that relies heavily on fossil fuels – and provide clear contrasts in terms of expected climate impacts. This selection helps illustrate the range of possible outcomes in a straightforward manner while keeping the analysis accessible and focused.

What are the SSPs?

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

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

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

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

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

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

marginally improves, while the challenges for addressing vulnerability to societal and environmental changes persist.

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

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

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

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

The IPCC Sixth report does not estimate the likelihood of the four tested scenarios. The rise in heat levels will depend on which mitigation pathway and policies countries collectively and independently pursue.[16]

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 Lebanon tomorrow.

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.

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 Lebanon

While the SSPs are developed as global scenarios, they provide critical insights for national decision-makers, including those in Lebanon. 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 Lebanon, 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, Lebanese 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 Lebanon 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 Lebanon to tailor its climate adaptation and economic policies to protect its citizens and secure a more stable, sustainable future.

2.4.3. Future heat conditions

The monthly maximum average environmental temperature and WBGT during the reference historical period (1985-2014) ranged between 20°C and 22.5°C (Figure 4). Across all SSPs, the analyses suggest 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), Lebanon will face increases of 2°C to 3°C. The scenarios with high emissions (SSP3-7.0 and SSP5-8.5) suggest more significant warming of up to 7.5°C. Without effective adaptation strategies, these would lead to significant health impacts and severely reduce the capacity to perform manual labour.

Figure 5 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. According to SSP1-2.6, there will likely be a moderate increase in temperature by 2040, generally around 1.5°C to 2.5°C. By 2060 and until the end of the century, the temperature increases could stabilize at around 3°C across most of Lebanon, with some hotter inland areas experiencing slightly higher temperature increases.

Based on the SSP2-4.5, a significant increase in temperature is expected by 2040 with temperature rises of up to 3°C in inland areas, and smaller increases in the coastal regions. As global climate action on emissions reduction is slower in this pathway, the temperature increases of 3°C to 4°C will spread throughout the country by 2060 and until the end of the century.

Figure 4. 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.

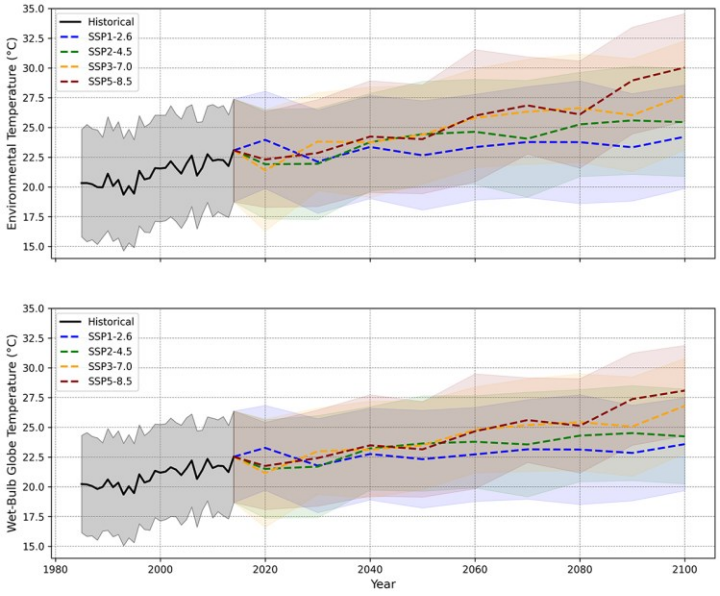
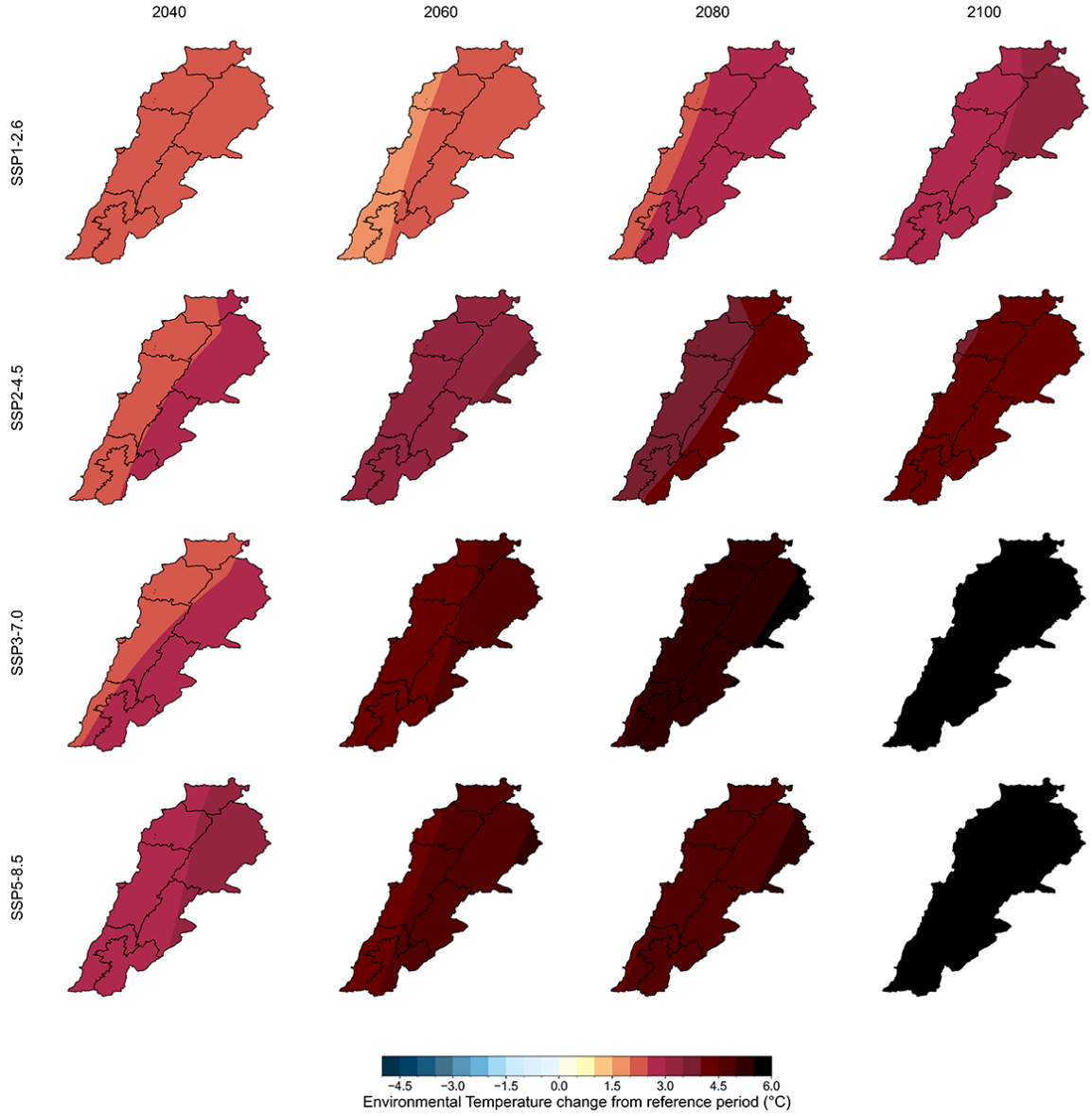


Figure 5. Change in the average maximum environmental temperature in Lebanon compared to the reference historical period (1985-2014) across the different SSPs and at different time points during this century.



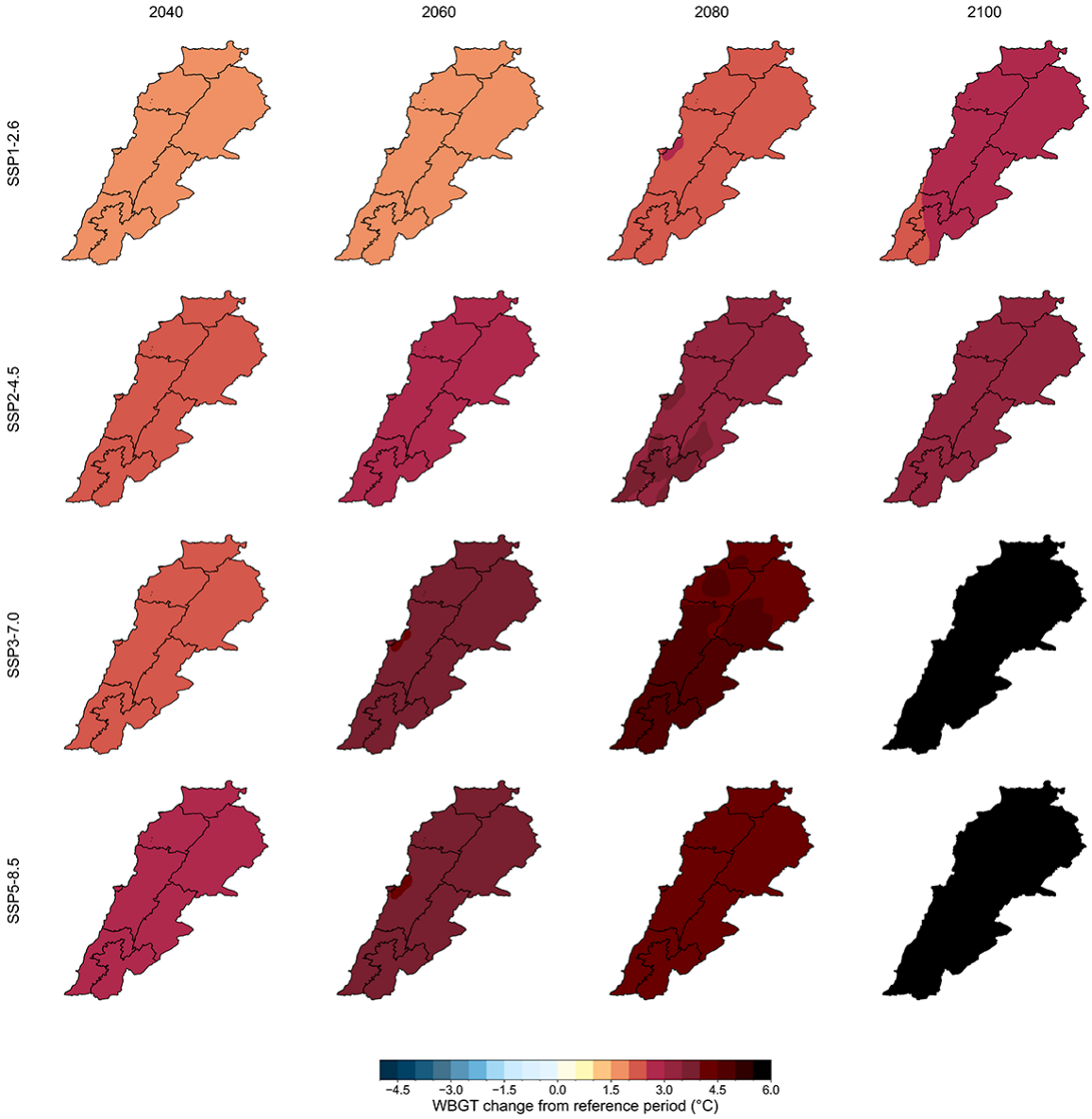
According to the SSP3-7.0, a more significant temperature rise of 4°C to 5°C is anticipated to emerge in many areas by 2060 and spread throughout the country by 2100. After 2080, Lebanon could face severe temperature rises, with much of the country experiencing increases of up to 6°C, which would have significant impacts on water resources, agriculture, and heat stress.

According to the SSP5-8.5, the initial temperature rise will be around 3°C to 3.5°C across the country. With continued fossil fuel use and unchecked emissions (assumed in this scenario), Lebanon will see a substantial rise in temperatures, reaching 4°C to 5°C by 2080. By the end of the century, this pathway projects Lebanon's temperatures increasing by over 6°C across all regions. This would represent severe climate impacts, including unmanageable heatwaves, water shortages, and disruptions to daily life and agricultural systems.

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 6. The results follow closely those for environmental temperature, which are discussed above. In brief, across all scenarios, the analyses suggest a clear warming

trend, with varying degrees of severity depending on the SSP. Even in the most optimistic scenario (SSP1-2.6), Lebanon will face WBGT increases of 2°C to 3.5°C in many regions.

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



Inland and southern regions of Lebanon are projected to experience the most significant WBGT increases toward the end of the century. Without strong climate mitigation (i.e., SSP3-7.0 and SSP5-8.5), by the end of the century, Lebanon could see WBGT rises of up to 6°C, which would lead to significant heat-health impacts as well as drastic reductions in the capacity to perform manual labour. These projections underscore the importance of implementing adaptation strategies to mitigate the impacts of rising heat levels in Lebanon.

3. Loss of work capacity by sector of activity

3.1. Overview of economic activity sectors

Lebanon's economy, once known for its vibrant service sector and status as a regional financial hub, has experienced significant setbacks in recent years due to a series of compounded crises, including political instability, the financial collapse in 2019, the COVID-19 pandemic, and the 2020 Beirut Port explosion, and most recently the military escalation on the border with Israel. These events have led to one of the most severe economic contractions in modern history, with Lebanon's nominal GDP plummeting from around $52 billion in 2019 to approximately $23.1 billion in 2021.[18] As a result, Lebanon was downgraded to lower-middle-income status by the World Bank. Key sectors of the economy include:

1. **Services:** The service sector is the dominant component of Lebanon's economy, contributing around 77% of GDP (Table 2) and employing about 75% of the workforce.[17] This sector includes tourism, banking, and education, but all have been heavily impacted by the recent crises. The banking sector, once a pillar of the Lebanese economy, has suffered from widespread capital controls and de facto currency devaluation, limiting its ability to function as a source of investment.[17] Tourism, which accounted for nearly 20% of GDP, has shown some signs of recovery during 2023.[17]
2. **Industry:** The industrial sector, which includes manufacturing and construction, historically played a significant role in Lebanon's economy but has drastically declined.[17] The sector employs around 21% of Lebanon's workforce and focuses primarily on food processing, metal products, and construction materials.[17]
3. **Agriculture:** The contribution of agriculture to Lebanon's GDP is relatively small, at around 8%, but it provides vital food security for many Lebanese households, especially during economic downturns.[18] The sector employs about 4% of the country's workforce and is concentrated in the production of fruits, vegetables, and other agri-food products.[17]

In summary, Lebanon's economy is heavily service-oriented, but recent crises have severely disrupted all sectors, leading to high unemployment and a sharp decrease in GDP. Despite some recovery signs in tourism, Lebanon faces significant challenges in revitalizing its economy and addressing structural weaknesses in industry and agriculture. At the time of writing the present document, the full overview of the devastating effects in terms of human, economic, social, and environmental losses from the military escalation between Israel and Hezbollah is not possible to estimate.

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

[18] Lebanon Economic Monitor - Fall 2023: In the Grip of a New Crisis (English). Lebanon Economic Monitor Washington, D.C.: World Bank Group.

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.[14] 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.[14,19]

Work intensity and metabolic heat production

The physical effort required for high-intensity work naturally produces metabolic heat.[14,20] When this internal heat generation combines with external (environmental) heat stress, the body's cooling mechanisms can be overwhelmed.[14] 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"[15] and it is a key factor in the observed loss of work time and, therefore, productivity.[21]

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[21,22] and increased error rates.[23] This occurs because workers should take more frequent breaks, reduce their pace, or even stop working to avoid heat-related health risks.[24] 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.[12,22]

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 Lebanon was estimated using a response function for workability, based on previous methods.[25] The estimated work capacity loss in Lebanon's agricultural, construction, manufacturing, mining and quarrying, services, as well as transport and trade sectors are illustrated in Figures 7-9. 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 due to heat stress in **agriculture** and **construction** (Figure 7) fluctuated between 7-12% in high-intensity work, and between 1% and 10% in low- and moderate-intensity work.

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[19] Kenny G.P., Wilson T.E., Flouris A.D., Fujii N. (2018). Heat exhaustion. Handbook of Clinical Neurology; 157: 505-529.
[20] 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.
[21] 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.
[22] 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.
[23] 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.
[24] 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.
[25] 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.

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 8-10% in high-intensity work, about 5% in moderate-intensity work, and 2-4% 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 15% in low-intensity work and exceeding 22% in high-intensity work by 2100, reflecting the severe impact of climate change and heat stress on work capacity.

In **manufacturing**, **mining and quarrying** (Figure 8), **services**, **transportation**, and **trade** (Figure 9), work capacity losses due to heat stress remained below 5% during the historical period. During this century climate change is not expected to cause significant work capacity losses in low-intensity work beyond the levels observed in the historical period. This is also the case for moderate- and high-intensity work under scenarios SSP1-2.6 and SSP2-4.5, which assume sustainability-focused global action. However, in SSP3-7.0 and SSP5-8.5, climate change will lead to additional work capacity losses reaching 5% in low-intensity work and exceeding 12% in high-intensity work by 2100, 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 23% higher at the end of the century compared to the average year during the historical period. 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 lower across all intensity levels. However, in scenarios where climate action is delayed or absent (SSP3-7.0, SSP5-8.5), work capacity losses increase significantly, particularly for high-intensity work.
- **Long-term trends:** regardless of the SSP, work capacity losses generally increase towards the latter half of the century, reflecting the long-term effects of climate change on work capacity in Lebanon.

This analysis emphasizes the need for targeted adaptation strategies, particularly for high-intensity labour, to mitigate work capacity losses in the context of increasing heat levels and climate change impacts. Also, the findings highlight the importance of ambitious global and national mitigation efforts.

Figure 7. Average work capacity loss (%) in Lebanon 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.

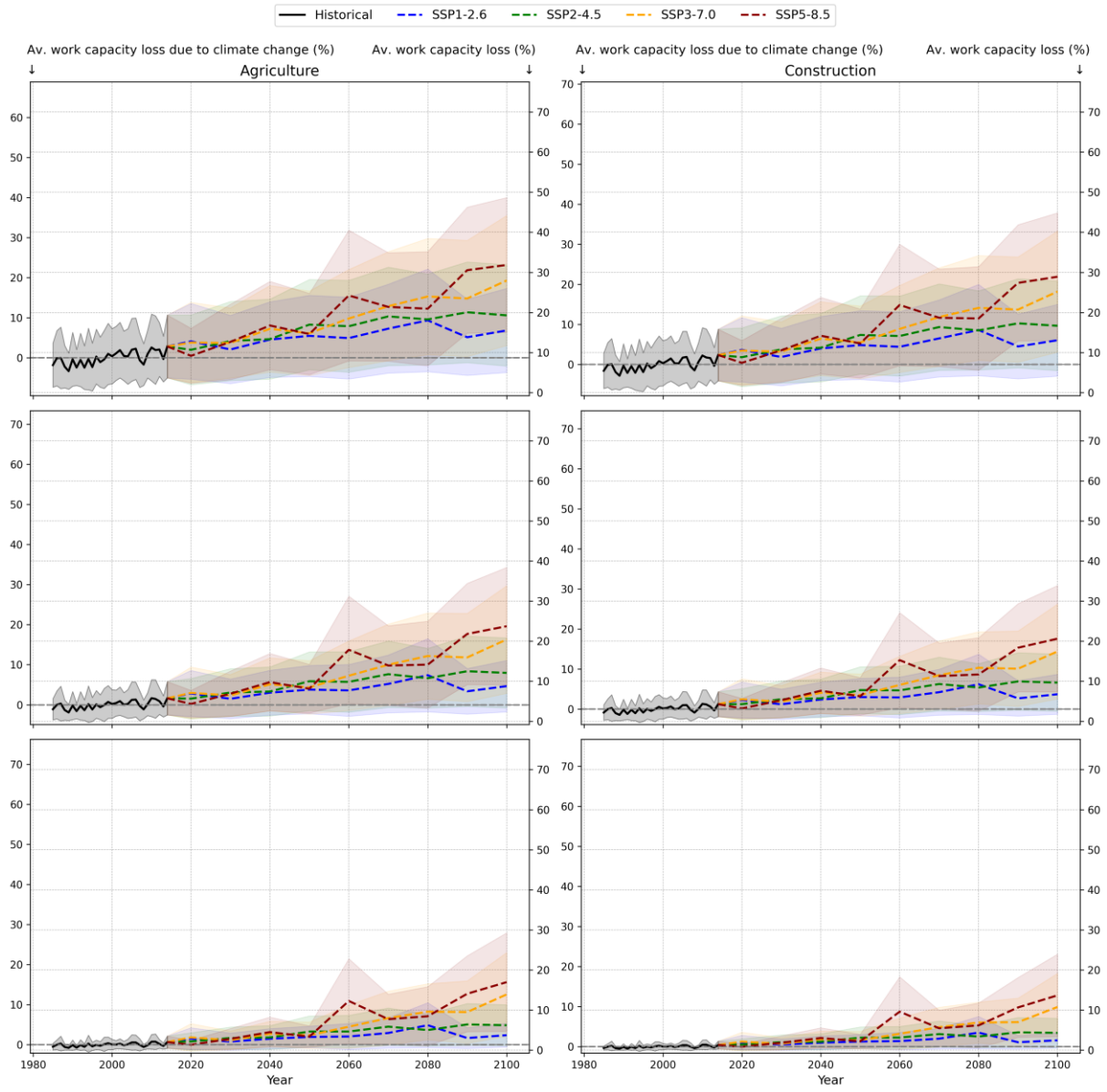


Figure 8. Average work capacity loss (%) in Lebanon during high- (top), moderate- (middle), and low- (bottom) intensity work in manufacturing (left graphs) as well as mining and quarrying (right graphs) during the reference historical period (1985-2014) and until 2100 across the different SSPs. Vertical 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.

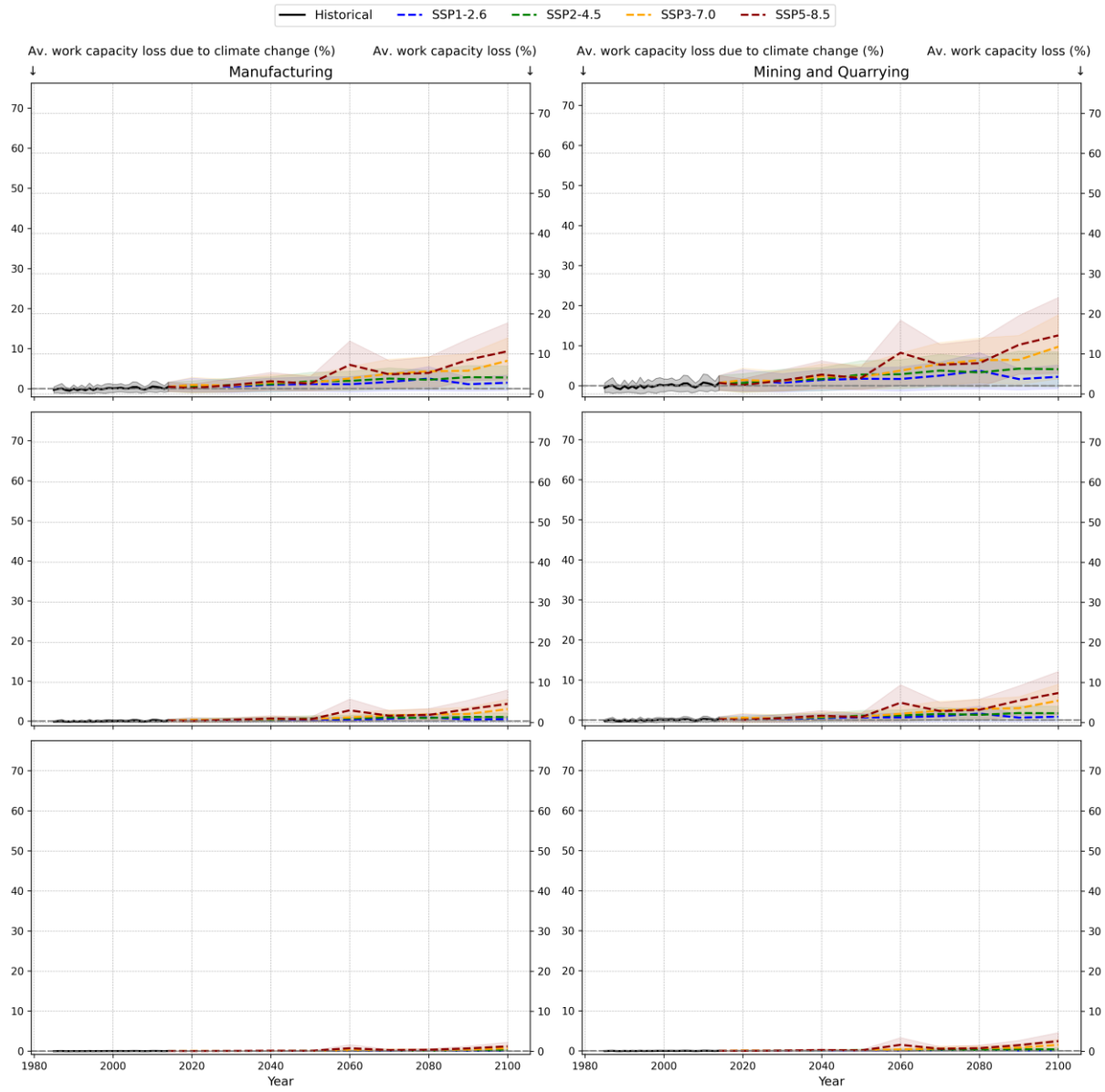
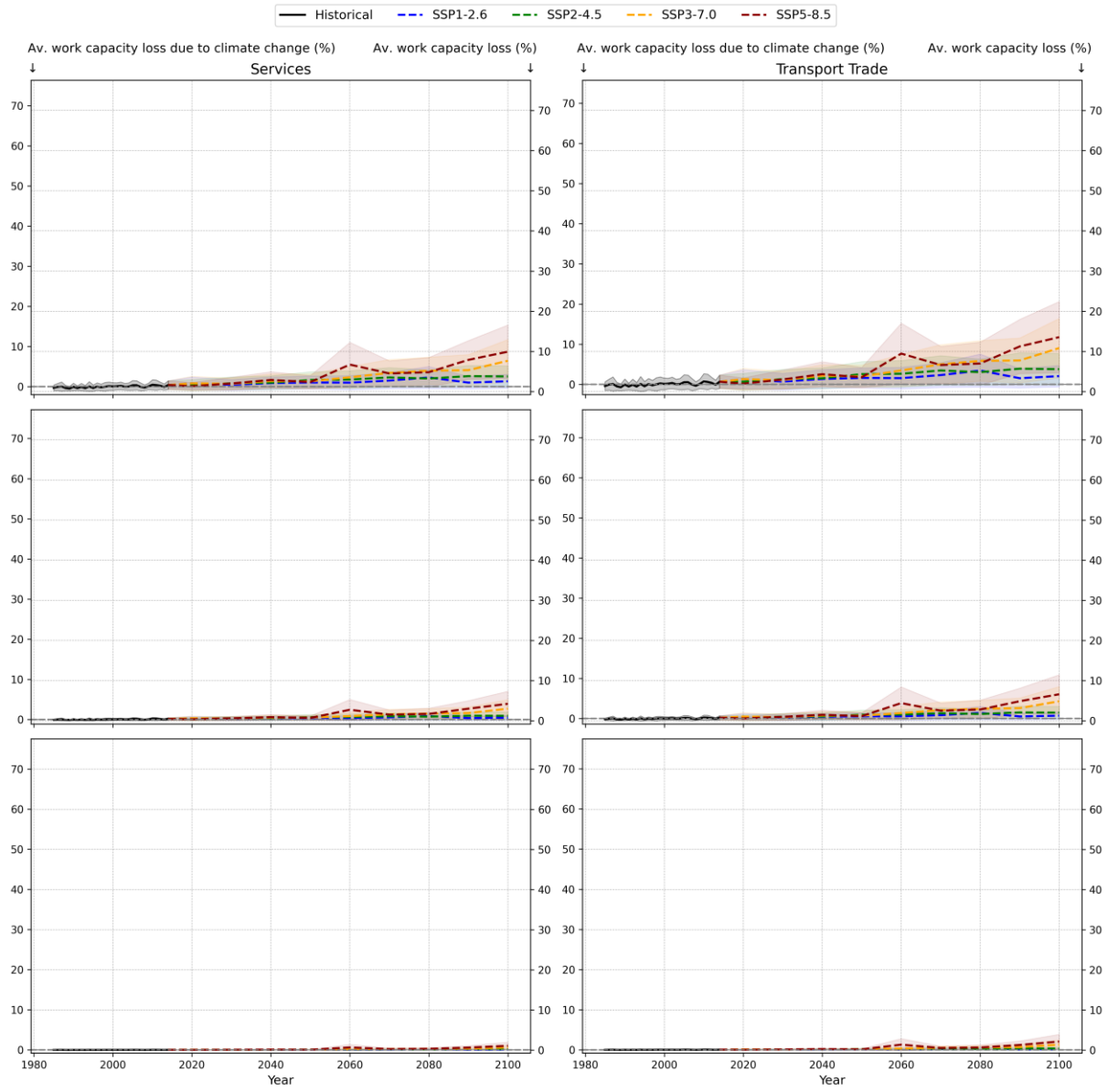


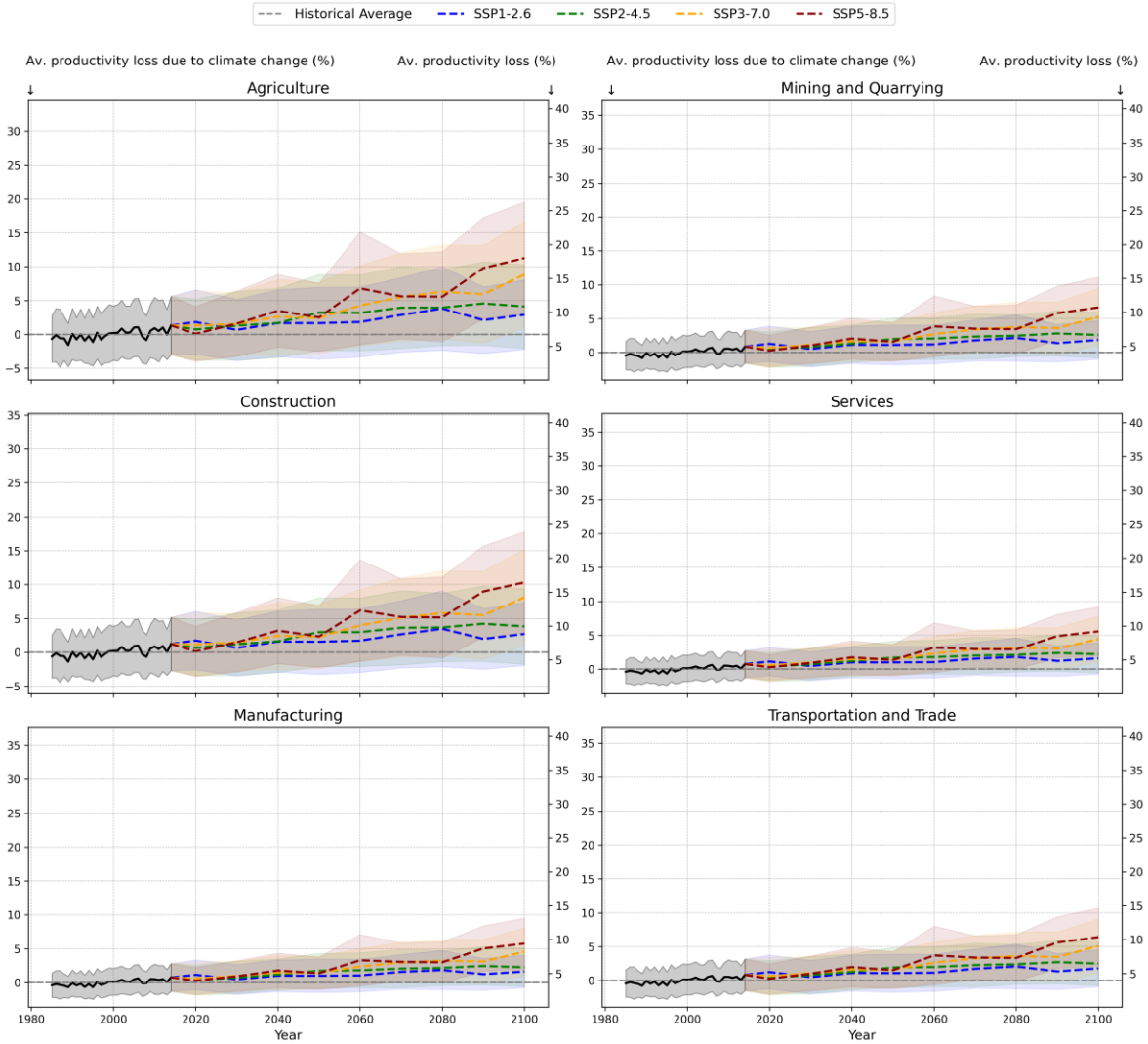
Figure 9. Average work capacity loss (%) in Lebanon during high- (top), moderate- (middle), and low- (bottom) intensity work in services (left graphs) as well as transportation and trade (right graphs) during the reference historical period (1985-2014) and until 2100 across the different SSPs. Vertical 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.[12,22,23,24] 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.

Figure 10. Average productivity loss in Lebanon 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.



The estimated productivity loss by sector due to climate change and heat stress under current and projected conditions is illustrated in Figure 10. In **agriculture** and **construction**, productivity loss due to heat stress

fluctuated between 5% and 8%, during the historical period. By 2100, under SSP1-2.6 and SSP2-4.5, productivity loss is expected to further increase by 3-5% 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 12% 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 4% to 6% during the historical period. Under SSP1-2.6 and SSP2-4.5, climate change is anticipated to further increase productivity loss by 2-3% 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 7% in these scenarios by 2100.

5. Economic and labour market impacts of climate change

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 signify 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 Lebanon lost 326 million USD more in 2023 compared to the average year during the reference historical period (1985-2014) (Table 3). The distribution of the GDP loss (in million USD) due to climate change across the country is illustrated in Figure 11. The map shows that losses are not even across the country. The largest losses occur along the coastal urban belt, and particularly in the area of Jounieh and Byblos, and the region connecting the two cities. This area, located just north of Beirut, is home to a high concentration of tourism-related businesses, resorts, and other service-oriented activities. The proximity to the Mediterranean Sea has made this area prime location for international tourism, with many businesses reliant on stable, favourable weather conditions for year-round activity.

The higher economic losses due to climate change in Jounieh and Byblos illustrate Lebanon's economic dependency on services. The regions of Jounieh and Byblos rely heavily on the services sector, which includes tourism, hospitality, and retail. The service sector accounted for more than two-thirds of Lebanon's GDP by 2019, and the concentration of these activities in coastal areas means that these zones are particularly vulnerable to climate change, which can significantly reduce productivity and raise operational costs for businesses dependent on favourable weather environmental conditions.[17] The higher impact of climate change on GDP in this region also reflects broader infrastructural challenges, as climate change affects power consumption (air conditioning, cooling systems), water availability, and transport systems. These combined effects contribute to the significant economic losses shown in the map, making the area between Jounieh and Byblos highly vulnerable to future climate impacts unless comprehensive adaptation measures are adopted.

Losses decline toward the north and the interior. Parts of the Bekaa and the far north show lower values in absolute terms because the local economic base is smaller. This does not mean low risk for workers. Outdoor tasks in agriculture and construction remain heat-exposed and productivity still drops even where the map shows smaller GDP reductions.

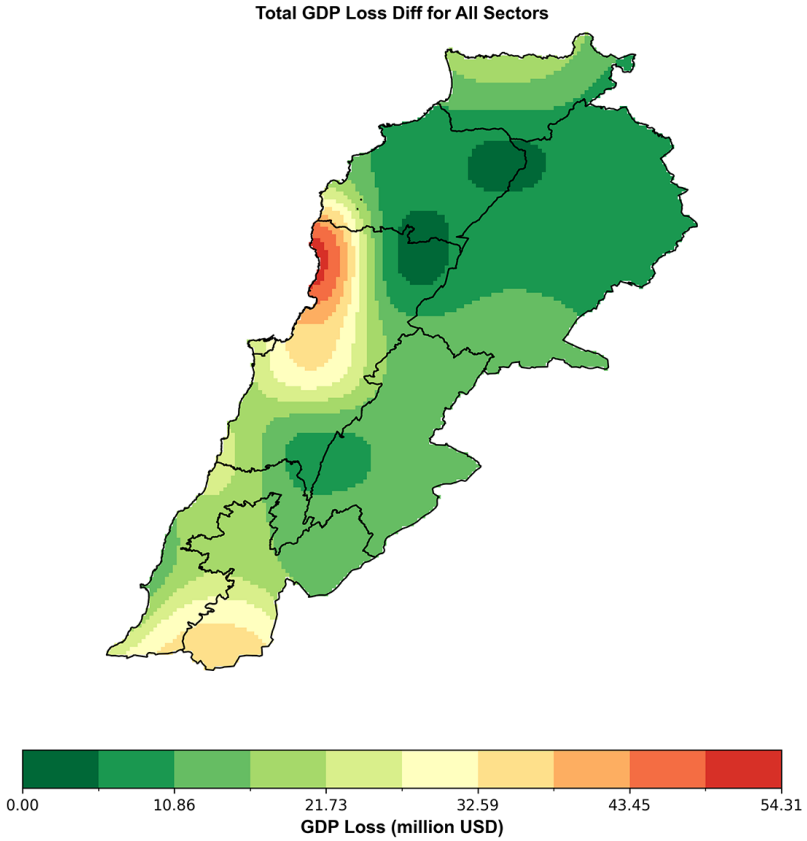
The pattern is national. Losses cluster where people and jobs are densest, but every region records some loss against the historical baseline. Moderate losses appear in the coastal south. Lighter losses appear in the far north and in parts of the eastern ranges. The gradient from the dense coast to the interior is clear.

The macro-economic implications of the present findings are important since reductions in available work time of key industries due to climate change can have significant macroeconomic effects. For example, the service

sector – which plays a key role in Lebanon's national production – loses a substantial portion of its effective work hours due to climate change and the cumulative effect leads to significant declines in overall GDP. This economic result underscores the importance of addressing heat stress induced by climate change, not only to protect worker health and productivity, but also to maintain economic stability and growth. The connection between reduced work time and GDP loss highlights the broader economic risks posed by rising heat stress due to climate change, emphasizing the importance of investing in heat mitigation and adaptation strategies to protect both worker well-being and the nation's economic prosperity.

The policy message is practical. Protect workers and firms in Beirut and the coastal regions where the absolute toll is highest. Use WBGT-based triggers for work and rest. Provide safe water, work breaks, shade, ventilation, and cooling. Improve indoor climate control in services, transport hubs, and factories. Support outdoor workers in agriculture and construction with earlier starts and longer midday breaks. Strengthen heat warning systems and public access to cool spaces in cities.

Figure 11. GDP loss across Lebanon 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. Importantly, the analysis takes into account the GDP volatility (total and industry-specific contribution) across the years. The real GDP in 2023 was 12.3% higher than the average year within the historical period (Table 2). However, both total GDP and industry-specific contributions to GDP have experienced marked volatility over the past decades. After the 2004

post-war recovery, GDP growth surged, averaging ~9% annually from 2007-2010 during reconstruction. Growth then decelerated to ~1.7% per year during 2011-2016, as the Syrian civil war and domestic instability dampened economic activity. At the start of 2019, Lebanon entered a severe economic crisis: the banking collapse and sovereign default, compounded by COVID-19 and the 2020 Beirut port explosion, led to an unprecedented contraction. The economy shrank by over 50% between 2019 and 2021. By 2024, real GDP remained nearly 40% below its 2019 level, reflecting one of the world's worst economic collapses in modern times.

As described in Section 3.1, the Lebanese economy is highly service-oriented, with services consistently contributing well above 70% of GDP since the 1980s. Compared to the average year within the historical period, services in 2023 grew by 18.4% and had a 4 percentage points higher contribution to GDP (Table 2). Notably, amid the post-2019 contraction, agricultural output held up and even grew in relative importance; its GDP share rose from 4.5% in the historical period to 7.7% in 2023 (Table 2). Transport and trade as well as mining and quarrying also grew, increasing their contribution to GDP by 0.2 and 0.1 percentage points, respectively.

The industrial sector (including manufacturing and construction) contributed roughly 7.6% of GDP in 2023, but it has declined significantly compared to the historical period (Table 2). Industrial output was hit hard by the crisis, with the sector's share of GDP dropping by 7.5 percentage points from the historical period to 2023. Construction activity, supported by real-estate booms in the late 2000s, stagnated after 2011 and collapsed after 2019, reflecting the broader financial turmoil. Overall, the construction industry shrank by ~50% from the historical period to 2023 (Table 2). Similarly, manufacturing's share of GDP steadily eroded in the last decade. It grew steadily in the 2000s, reaching a peak of about USD 4.4 billion (constant 2015 USD) in 2013. Thereafter, the sector entered a prolonged contraction: real manufacturing output fell to roughly USD 3.1 billion by 2019 and USD 1.6 billion in 2020. This collapse was marked by a -48% contraction in 2020 alone, amid compounded economic crises. Overall, manufacturing shrank by ~40% from the historical period to 2023 (Table 2).

Table 2. GDP and contribution of each sector to GDP in Lebanon during 2023 and the reference historical period 1985-2014.

Sector	**1985-2014**		**2023**		**Change[1]**	
	(M USD)[2]	*(%)*	*(M USD)[3]*	*(%)*	*(M USD)[3]*	*(%)*
Agriculture	1,264	4.5	2,449	7.7	1,185	93.8
Construction	1,634	5.8	821	2.6	-813	-49.8
Manufacturing	2,626	9.3	1,579	5.0	-1,047	-39.9
Mining and Quarrying	906	3.2	1,041	3.3	134	14.8
Services	20,538	72.6	24,323	76.6	3,785	18.4
Transport and Trade	1,295	4.6	1,528	4.8	233	18.0
Total GDP	**28,263**		**31,740**		**3,478**	**12.3**

[1] relative to the historical period; [2] average of the period 1985-2014 (million USD, fixed 2015 prices); [3] million USD, fixed 2015 prices.

The impact of rising workplace heat stress due to climate change on each sector of economic activity is shown in Table 3. The GDP losses in the service sector far outweigh those from all other sectors, representing 91.6% of the added total GDP losses compared to an average year during the historical period. Agriculture is also heavily impacted, with 106 additional million USD lost due to heat stress during 2023 in relation to an average year during the historical period (Table 3). On the other hand, construction and manufacturing show 18.5% and 13.8% less impacts of workplace heat stress during 2023, compared to an average year during the historical period. This was regardless of the intensified climate change, and was caused by the large shrinking of these industries during the last decade (Table 2).

Table 3. 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)[1]	*(distribution; %)*
Agriculture	-106.1	32.5
Construction[2]	60.2	-18.5
Manufacturing[2]	44.9	-13.8
Mining and Quarrying	-6.9	2.1
Services	-298.8	91.6
Transport and Trade	-19.7	6.1
Total GDP change	-326.3	

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

[2] regardless of climate change, the economic impact of workplace heat stress was less in 2023 than in historical period due to industry shrinking (Table 2).

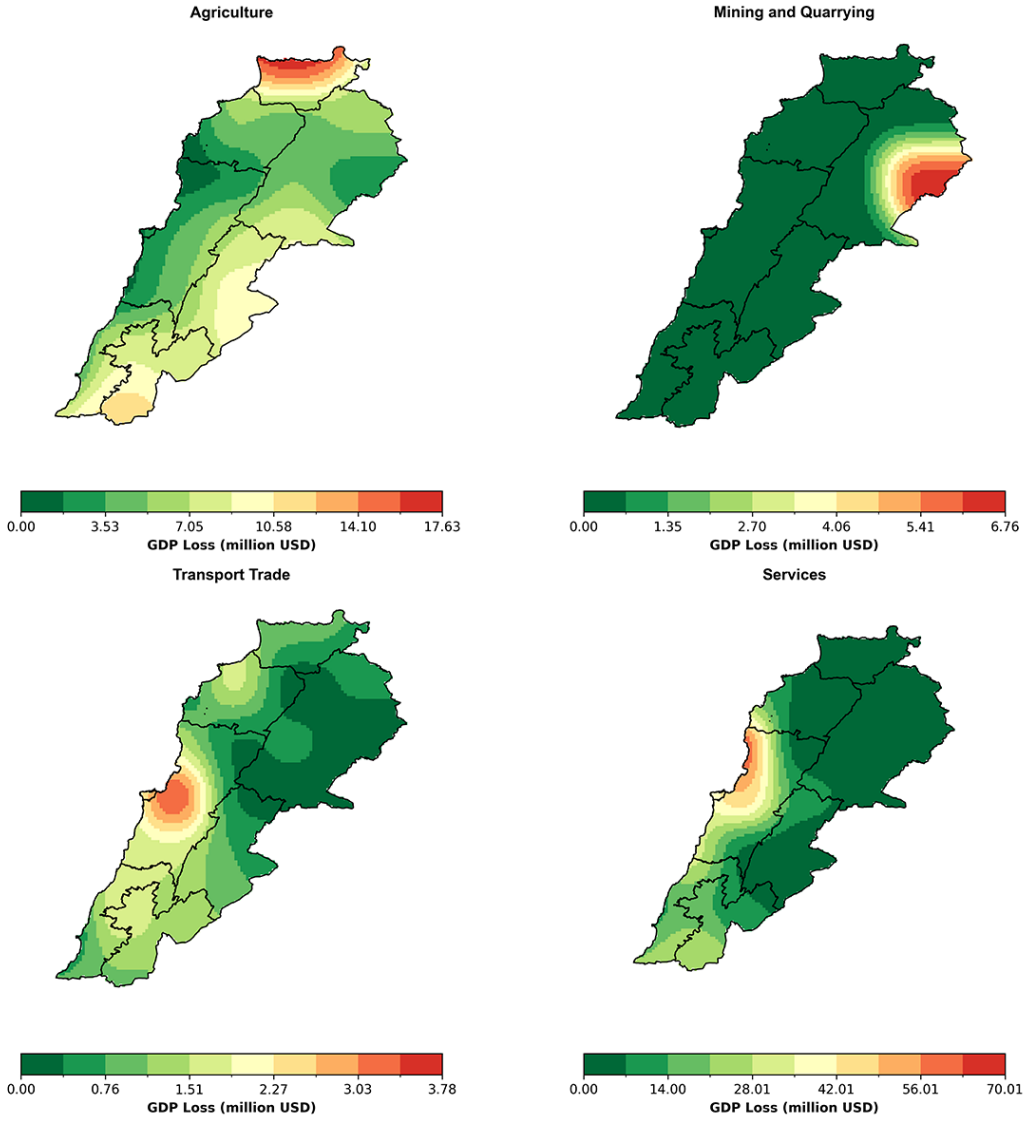
The regional distribution of the impact of rising workplace heat stress due to climate change on each sector of economic activity is illustrated geographically in Figure 12. It is important to note that colour scales differ by panel, so intensity cannot be directly compared. The services map uses a much wider range because of the size of that sector in the national economy. Also, the impacts for construction and manufacturing are not displayed, since they were less in 2023 than the historical period due to severe industry shrinking (Table 2).

The analysis shows that services carry the largest absolute loss. The hotspot sits in the area between Jounieh and Byblos and spills into nearby districts. The losses reach about 70 million USD, far above those observed in the other sectors. This reflects the weight of retail, hospitality, public services, finance, ports and tourism in and around the capital, and the added effect of urban heat. Agriculture shows a different pattern. Losses line the main farming areas, especially the Akkar plain in the far north, parts of the Bekaa valley, and pockets along the southern coast. Losses reach 17.6 million USD as outdoor and high-effort tasks make these areas sensitive to hot and humid conditions at mid-day.

Transport and trade losses cluster around the main logistics axis. The strongest impacts appear near the Beirut-Saida-Tyre coastal corridor, in Tripoli, as well as along key inland routes. These losses reach 3.8 million USD demonstrating how heat slows loading, handling, and road work even when activity continues. Mining and quarrying losses are very localized. A clear hotspot appears along the main quarry belt in the interior, with losses reaching 6.8 million USD.

Taken together, these sector-based results emphasize the need for climate adaptation strategies, particularly in key economic areas such as services, agriculture, transport, and trade, to mitigate the economic impacts of climate change. The analysis indicates three main patterns. The capital region is the core loss area because it hosts most service activity. Farming belts in the north and parts of the Bekaa and the south show clear losses driven by outdoor work. Logistics and quarrying losses are smaller in absolute terms but concentrated along the main corridors and extraction sites.

Figure 12. GDP loss across Lebanon due to rising workplace heat stress caused by climate change, between 2023 and the baseline historical period 1985-2014, in selected sectors of economic activity (excluding construction and manufacturing; see text). Note: due to the dominance of the service sector in Lebanon'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 4. Lebanon'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 4.2% and 5.1% 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 2.6 billion USD in 2040 and 5.6 billion USD in 2060. Under a "middle-of-the-road" scenario (SSP2-4.5), the contraction deepens from 4.0% (2.1 billion USD) in 2040 to 5.9% (5.6 billion USD) in 2060, while a regional-rivalry world (SSP3-7.0) will drastically increase the burden to 5.6% by 2060. Given the slow economic growth foreseen in SSP3 (see Section 2.4.2), this higher relative loss is equal to 3.2 billion USD. Should fossil-fuel development continue unabated (SSP5-8.5), rising workplace heat

stress could cut 8.4% (12.9 billion USD) off annual national output by 2060, eliminating the cumulative GDP value of several medium-sized manufacturing subsectors.

The sectoral pattern is uneven but consistent across pathways. Services, the backbone of the Lebanese economy, bears most of the losses: 3.3% in 2040 under SSP1-2.6, rising to 6.4% in 2060 under SSP5-8.5. Manufacturing as well as transport and trade absorb steady declines that deepen from 0.3% (SSP1-2.6, 2040) to 0.7% (SSP5-8.5, 2060), reflecting high indoor heat loads and partial air-conditioning coverage. Agriculture registers consistent negative impacts which intensify as warming accelerates, suggesting growing stress on farm labour productivity. Construction shows marginal negative impacts because the indicator is calculated against a post-crisis low baseline, yet any sectoral rebound would quickly expose vulnerability, eliminating this artefactual gain.

Three policy conclusions follow. First, the steep scenario gradient confirms that ambitious global mitigation could avert roughly two-thirds of projected GDP losses by 2060. Second, domestic adaptation should prioritise heat-proofing the services economy, particularly retail, hospitality and public administration, where the absolute loss is greatest. This implies accelerated investment in efficient cooling, urban heat-island management and flexible work scheduling. Third, sector-specific labour regulations should anticipate that recovery in construction and expansion of agro-processing will intensify exposure to workplace heat stress. Therefore, integrating heat stress thresholds into building codes, agricultural extension services and social-protection schemes will be critical. Anchoring these measures in Lebanon's forthcoming National Adaptation Plan and Decent Work Country Programme will help safeguard both competitiveness and worker welfare as temperatures rise.

Table 4. Annual impact of rising workplace heat stress caused by climate change on GDP in Lebanon 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	-99.6	-0.16	-247.2	-0.23
	SSP2-4.5	-72.8	-0.14	-248.0	-0.26
	SSP3-7.0	-43.4	-0.11	-136.9	-0.24
	SSP5-8.5	-185.1	-0.24	-634.4	-0.41
Construction	SSP1-2.6	-56.2	-0.09	-205.1	-0.19
	SSP2-4.5	-29.9	-0.06	-199.0	-0.21
	SSP3-7.0	3.0	0.01	-88.3	-0.16
	SSP5-8.5	-142.8	-0.19	-590.9	-0.38
Manufacturing	SSP1-2.6	-222.1	-0.35	-481.8	-0.44
	SSP2-4.5	-179.3	-0.33	-485.0	-0.50
	SSP3-7.0	-108.9	-0.28	-270.0	-0.47
	SSP5-8.5	-360.7	-0.47	-1115.6	-0.73
Mining and Quarrying	SSP1-2.6	17.8	0.03	14.4	0.01
	SSP2-4.5	18.3	0.03	13.8	0.01
	SSP3-7.0	18.8	0.05	16.3	0.03
	SSP5-8.5	16.1	0.02	5.4	0.00
Services	SSP1-2.6	-2085.2	-3.31	-4328.7	-3.97
	SSP2-4.5	-1723.0	-3.20	-4360.7	-4.53
	SSP3-7.0	-1114.1	-2.86	-2513.3	-4.41
	SSP5-8.5	-3268.4	-4.29	-9753.9	-6.34
Transport and Trade	SSP1-2.6	-179.9	-0.29	-360.5	-0.33
	SSP2-4.5	-150.0	-0.28	-361.3	-0.38
	SSP3-7.0	-103.0	-0.26	-214.8	-0.38
	SSP5-8.5	-277.9	-0.37	-808.8	-0.53
TOTAL	SSP1-2.6	-2,625.24	-4.17	-5,608.85	-5.14
	SSP2-4.5	-2,136.79	-3.97	-5,640.13	-5.86
	SSP3-7.0	-1,347.58	-3.46	-3,206.99	-5.63
	SSP5-8.5	-4,218.75	-5.54	-12,898.27	-8.39

[1] million USD, fixed 2015 prices.

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

5.3. Current labour market impacts

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

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

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

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

The analysis used data for 2023 to describe the current impact of rising heat stress due to climate change on Lebanon'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 5 show that the impact of climate change on Lebanon's labour market is significant, with over 10 thousand more jobs lost due to workplace heat stress during 2023 compared to the average year during the historical period. The analysis reflects a seasonal pattern where 73% of the impacts occur in Q3, mirroring the period of most intense heat. Nearly two-thirds (62%) of job losses are concentrated in services, 15% occur in construction, as well as about 9%, 8%, and 6% in manufacturing, transport and trade, as well as agriculture, respectively. 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 Lebanon.

Table 5. 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 Lebanon, calculated as the change between 2023 and the reference historical period 1985-2014. Negative values indicate losses vs reference; positive values indicate gains (reduced heat impact) vs reference.

Sector	Period	Available Work Hours (n)	Change in Work Hours		Change in Jobs (FTE)
			(n)	(% FTE)	
Agriculture	Q1	27,857,943	67,136	0.24	33
	Q2	28,180,000	-220,472	-0.78	-110
	Q3	28,502,057	-1,054,915	-3.70	-526
	Q4	28,502,057	14,487	0.05	7
	Year	113,042,057	-1,193,764	-1.06	-595
Construction	Q1	58,885,246	47,708	0.08	24
	Q2	59,566,000	-532,092	-0.89	-265
	Q3	60,246,754	-2,354,793	-3.91	-1,174
	Q4	60,246,754	-208,513	-0.35	-104
	Year	238,944,754	-3,047,690	-1.28	-1,519
Manufacturing	Q1	73,368,806	-38,014	-0.05	-19
	Q2	74,217,000	-322,040	-0.43	-161
	Q3	75,065,194	-1,360,329	-1.81	-678
	Q4	75,065,194	-126,897	-0.17	-63
	Year	297,716,194	-1,847,281	-0.62	-921
Mining and Quarrying	Q1	250,603	166	0.07	0
	Q2	253,500	-492	-0.19	-0
	Q3	256,397	-2,951	-1.15	-1
	Q4	256,397	190	0.07	0
	Year	1,016,897	-3,088	-0.30	-2
Services	Q1	472,775,883	-421,613	-0.09	-210
	Q2	478,241,500	-2,452,447	-0.51	-1,223
	Q3	483,707,117	-8,851,577	-1.83	-4,413
	Q4	483,707,117	-875,206	-0.18	-436
	Year	1,918,431,617	-12,600,843	-0.66	-6,282
Transport and Trade	Q1	49,476,023	-25,439	-0.05	-13
	Q2	50,048,000	-301,812	-0.60	-150
	Q3	50,619,977	-1,105,753	-2.18	-551
	Q4	50,619,977	-133,578	-0.26	-67
	Year	200,763,977	-1,566,582	-0.78	-781
TOTAL	Q1	682,614,503	-370,056	-0.05	-184
	Q2	690,506,000	-3,829,355	-0.55	-1,909
	Q3	698,397,497	-14,730,319	-2.11	-7,343
	Q4	698,397,497	-1,329,517	-0.19	-663
	Year	2,769,915,497	-20,259,248	-0.73	-10,099

n: number; FTE: full-time equivalent.

5.4. Future labour market impacts

Table 6 shows the annual projected labour market impacts of rising heat stress due to climate change during 2040 in each sector of economic activity and across the different SSPs, in relation to the reference historical period 1985-2014. The projected labour-time losses attributable to climate-induced heat stress grow markedly with the global emissions trajectory and are already substantial for Lebanon by 2040. Model results indicate that, relative to the 1985-2014 baseline, the economy will lose the equivalent of 21,700 full-time jobs under a low-emissions pathway (SSP1-2.6). The losses rise to 25,500 full-time jobs under SSP2-4.5, and almost 35,000-36,500 under the high-emissions scenarios (SSP3-7.0 and SSP5-8.5). In proportional terms this represents a 2.1% contraction in total available labour time under the most optimistic scenario and 3.5% under unabated fossil-fuel development.

The burden is highly concentrated in the services sector, which accounts for 13,700 FTE losses in SSP1-2.6, rising to nearly 22,500 in SSP5-8.5, roughly 62% of the national total. Services are particularly exposed because much of Lebanon's retail, hospitality and informal urban commerce occurs in environments with limited climate control. Construction ranks second, with losses of 3,100-5,500 FTEs across the scenario range, reflecting the sector's outdoor work intensity and the physiological limits of heavy manual labour in high humid-heat conditions. Manufacturing follows with 2,100-3,500 FTE losses, suggesting that existing ventilation and cooling measures in workshops and small factories remain insufficient to offset rising WBGT. Losses in transport and trade (-1,600 to -2,700 FTEs) as well as agriculture (-1,100 to -2,300 FTEs) are smaller in absolute terms but remain proportionately significant given those sectors' reduced post-crisis employment base. Mining and quarrying show minimal impacts, underscoring the advantage of mechanisation and limited workforce size.

Table 7 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 21,000-65,000 full-time jobs from Lebanon's economy each year, depending on the global emissions pathway. Model results show that under the Paris-consistent trajectory (SSP1-2.6) Lebanon will lose 21 thousand FTEs, or about 2% of total labour time. The toll rises sharply to over 38 thousand FTEs under SSP2-4.5, 55 thousand under SSP3-7.0, and peaks at nearly 65 thousand under SSP5-8.5, where heat cuts more than 6% of aggregate work hours.

Losses are highly concentrated in the services sector, reflecting its dominance in employment and the prevalence of heat-exposed retail, hospitality and informal urban activities. In 2060, services will lose over 13 thousand FTEs in the low-emissions scenario, climbing to nearly 40 thousand FTEs in the high-emissions scenario, about 61% of the national total. Construction, characterised by heavy outdoor labour, ranks second, with loses escalating from 3,069 to 9,990 FTEs across the scenario range. Manufacturing, where small workshops often lack adequate cooling, loses 2,039-6,206 FTEs, while agriculture is expected to record 1,225-4,327 FTE losses, indicating rising physiological impacts on field work. Transport and trade show comparable patterns (1,573-4,614 FTEs), whereas mining and quarrying remain marginal (fewer than a dozen FTEs) owing to mechanisation and limited labour market size.

Table 6. 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	102,568,217	-2,278,620	-2.22	-1,136
	SSP2-4.5		-2,404,487	-2.34	-1,199
	SSP3-7.0		-4,063,660	-3.96	-2,026
	SSP5-8.5		-4,531,474	-4.42	-2,259
Construction	SSP1-2.6	180,887,349	-6,177,650	-3.42	-3,080
	SSP2-4.5		-6,845,227	-3.78	-3,412
	SSP3-7.0		-10,114,535	-5.59	-5,042
	SSP5-8.5		-11,120,151	-6.15	-5,543
Manufacturing	SSP1-2.6	213,405,994	-4,246,398	-1.99	-2,117
	SSP2-4.5		-5,108,522	-2.39	-2,547
	SSP3-7.0		-6,956,970	-3.26	-3,468
	SSP5-8.5		-7,106,049	-3.33	-3,542
Mining and Quarrying	SSP1-2.6	998,846	-5,223	-0.52	-3
	SSP2-4.5		-5,384	-0.54	-3
	SSP3-7.0		-9,618	-0.96	-5
	SSP5-8.5		-11,034	-1.10	-6
Services	SSP1-2.6	1,452,309,634	-27,548,449	-1.90	-13,733
	SSP2-4.5		-33,090,136	-2.28	-16,496
	SSP3-7.0		-43,766,669	-3.01	-21,818
	SSP5-8.5		-45,093,476	-3.10	-22,479
Transport and Trade	SSP1-2.6	166,063,114	-3,207,131	-1.93	-1,599
	SSP2-4.5		-3,771,403	-2.27	-1,880
	SSP3-7.0		-5,111,272	-3.08	-2,548
	SSP5-8.5		-5,315,390	-3.20	-2,650
TOTAL	SSP1-2.6	2,116,233,154	-43,463,472	-2.05	-21,667
	SSP2-4.5		-51,225,160	-2.42	-25,536
	SSP3-7.0		-70,022,723	-3.31	-34,907
	SSP5-8.5		-73,177,574	-3.46	-36,479

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

Table 7. 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	102,568,217	-2,456,658	-2.40	-1,225
	SSP2-4.5		-4,461,444	-4.35	-2,224
	SSP3-7.0		-6,799,855	-6.63	-3,390
	SSP5-8.5		-8,680,509	-8.46	-4,327
Construction	SSP1-2.6	180,887,349	-6,156,394	-3.40	-3,069
	SSP2-4.5		-10,847,931	-6.00	-5,408
	SSP3-7.0		-16,110,007	-8.91	-8,031
	SSP5-8.5		-20,039,160	-11.08	-9,990
Manufacturing	SSP1-2.6	213,405,994	-4,091,207	-1.92	-2,039
	SSP2-4.5		-7,568,835	-3.55	-3,773
	SSP3-7.0		-11,252,732	-5.27	-5,610
	SSP5-8.5		-12,449,277	-5.83	-6,206
Mining and Quarrying	SSP1-2.6	998,846	-5,434	-0.54	-3
	SSP2-4.5		-11,065	-1.11	-6
	SSP3-7.0		-16,275	-1.63	-8
	SSP5-8.5		-21,770	-2.18	-11
Services	SSP1-2.6	1,452,309,634	-26,183,940	-1.80	-13,053
	SSP2-4.5		-47,884,901	-3.30	-23,871
	SSP3-7.0		-68,872,949	-4.74	-34,333
	SSP5-8.5		-79,371,470	-5.47	-39,567
Transport and Trade	SSP1-2.6	166,063,114	-3,155,008	-1.90	-1,573
	SSP2-4.5		-5,556,586	-3.35	-2,770
	SSP3-7.0		-8,149,180	-4.91	-4,062
	SSP5-8.5		-9,256,512	-5.57	-4,614
TOTAL	SSP1-2.6	2,116,233,154	-42,048,641	-1.99	-20,961
	SSP2-4.5		-76,330,761	-3.61	-38,051
	SSP3-7.0		-111,200,999	-5.25	-55,434
	SSP5-8.5		-129,818,698	-6.13	-64,715

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

Policy messages emerging from the macro-economic analysis

- **Global mitigation matters**. The gap between SSP1-2.6 and SSP5-8.5 amounts to more than 44,000 saved jobs annually by 2060, underscoring the macro-labour dividend of achieving a 2°C climate goal.

- **Services, manufacturing, and construction drive vulnerability**. Targeted adaptation, such as high-efficiency cooling retrofits, heat-resilient urban design, compulsory rest-break schedules and flexible hours, 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 Lebanon'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 Lebanon

Lebanon's adaptation to climate risks can be strengthened, particularly in terms of protecting workers from extreme heat and other climate-related hazards. The country's vulnerability highlights the need to adopt conventions that would support workplace safety under changing environmental conditions. By aligning more closely with ILO's OSH conventions, Lebanon will better integrate climate-resilient workplace practices, which will mitigate productivity losses and health risks, especially in sectors such as agriculture and construction where heat stress is most prevalent.

To date, Lebanon has ratified 51 ILO conventions, including 7 of the 10 fundamental ones.[26] However, key OSH conventions relevant to managing heat stress have not been ratified by Lebanon. These include:

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

- **Convention No. 161** (Occupational Health Services), emphasizing the provision of occupational health services. This Convention ensures access to occupational health services capable of monitoring and managing health impacts from environmental factors, and would reinforce Lebanon'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 lack of ratifying and aligning with ILO's OSH Conventions limits Lebanon's framework for comprehensive improvements in OSH, particularly concerning heat-related policies. This gap underscores the importance of incorporating climate adaptation within existing OSH frameworks to protect workers from rising heat stress. Given Lebanon's vulnerability to climate change and rising levels of heat stress, as demonstrated in the present study, ratifying the above as well as other ILO Conventions will significantly contribute to the management of heat stress. Also, including these Conventions in Lebanon's OSH policies could enhance national resilience by promoting regular workplace risk assessments and updating safety protocols to manage rising heat levels. Such measures could help Lebanon prepare for projected increases in heat stress and other climate risks, creating a safer and more resilient work environment. Moreover, ratifying and implementing these OSH Conventions aligns with Lebanon's climate and development goals. Integrating OSH standards in climate adaptation supports Lebanon's commitment to the Paris Agreement by fostering a just transition for workers, supporting the country's resilience to climate impacts, strengthening both worker protections and economic stability.

6.2. Policy recommendations for climate adaptation

Rising workplace heat stress is a major driver of reduced labour productivity and loss of working hours in Lebanon, particularly in physically demanding sectors such as construction, agriculture, and manufacturing. In

[26] https://normlex.ilo.org/dyn/nrmlx_en/f?p=1000:11200:0::NO:11200:P11200_COUNTRY_ID:103147

a Consultation Meeting carried out as part of the development of this study, local stakeholders also noted that workplace heat stress is associated with increased absenteeism, health outcomes, and discomfort, leading to reduced enterprise efficiency. They also highlighted additional economic pressures including increased social protection expenditures related to healthcare and compensation. Overall, local stakeholders identified workplace heat stress as a threat to livelihoods, particularly in the informal economy, where reduced productivity and health risks translate directly into income loss and job insecurity. Environmental degradation and deteriorating working conditions were also linked to increased rural-urban and cross-border migration pressures.

To strengthen Lebanon's climate resilience and to safeguard worker health, Lebanon could consider further aligning its climate adaptation policies with ILO OSH standards. Adhering to these standards will create a robust framework for managing heat stress and other climate-related occupational risks, particularly in the country's sectors highly vulnerable to heat levels, such as services, agriculture, construction, and manufacturing. This alignment with ILO OSH standards includes:

1. **Development of National Heat-Stress Guidelines:** Lebanon is encouraged to work towards establishing national heat stress guidelines that align with recent ILO recommendations[1] on the prevention and mitigation of heat stress in the workplace, as well as those in Convention No. 155 (Occupational Safety and Health), which mandates workplace policies to prevent accidents and illnesses, and Convention No. 161 (Occupational Health Services), emphasizing the provision of adequate health services for workers. These guidelines should adopt the general OSH protection framework for heat stress recommended by the ILO[1] that includes, as a minimum standard, the following 10 basic protection requirements (grouped based on ILO's hierarchy of controls):

   - **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:** Lebanon is encouraged to incorporate continuous monitoring and risk assessment protocols 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 that many workplaces lack basic infrastructure, such as cooling facilities, shaded areas, access to potable water and appropriate sanitation. In this light, employers should be encouraged to implement preventive measures for minimizing heat exposure risks. This should include, at a minimum, the development of a nation-wide early warning system, modified work hours during extreme heat, access to cooling solutions, and training for both employers and workers on identifying and responding to heat-related illnesses. Aligning with ILO's Decent Work Agenda, these measures would enhance working conditions and uphold workers' rights to a safe and healthy workplace, particularly critical in Lebanon's agriculture and construction sectors, where exposure to high heat exposure is frequent.

4. **Integration of Heat Stress into National OSH Policies:** A key aspect involves explicitly incorporating heat stress as a key occupational hazard in Lebanon's 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]

   There is also a need for inclusive and structured coordination involving a broad range of actors. A central platform could be created to map stakeholders, consolidate ongoing initiatives, and promote coherent national action on workplace heat stress and OSH. Key ministries to be engaged in this process could include Agriculture, Economy and Trade, Environment, Finance, Public Health, Interior and Municipalities, as well as Social Affairs. Research and academic institutions could also contribute to evidence-based policymaking, alongside national agencies related to labour, census and statistics, investment, and meteorology. International partners, including the ILO, UN system agencies, development partners, climate organisations, international experts in workplace heat stress, as well as labour and human rights organisations, represent important sources of technical support, normative guidance, and good-practice exchange. Knowledge sharing through Mediterranean and/or South-South and triangular cooperation represents another means of adapting successful models from countries with similar climatic and economic conditions.

   Actions under the Lebanon's Third Nationally Determined Contribution should be aligned with labour, OSH, and productivity objectives. Legislative enforcement could be strengthened by updating OSH regulations to explicitly cover climate-related risks and sector-specific exposure thresholds. Greater transparency could be encouraged through enterprise-level reporting on workplace heat conditions and mitigation measures.

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, particularly in sectors most vulnerable to heat stress. It is important for Lebanon's health services to 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] Re-skilling and lifelong learning programmes, including recognition of prior learning, would greatly benefit workers whose jobs are at risk due to workplace heat stress or climate-related economic shifts. Expanding social protection measures for heat-affected workers, particularly those in informal and seasonal employment, could be further emphasised, together with gender-responsive interventions, supported by targeted research, to better understand and address differentiated impacts. National awareness campaigns could 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 incentive 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.

By adopting the above ILO-aligned policy recommendations, Lebanon 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 Lebanon'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 Lebanon. In light of the evidence presented in this study, Lebanon is encouraged 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, Lebanon 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, 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.

Integrating workplace heat stress prevention into the national OSH framework would require, as a first and essential step, amending the labour law to explicitly include agricultural workers, who are currently excluded from full legal protection. Extending the scope of labour legislation to cover agricultural employment would be

a prerequisite for establishing clear protection mechanisms, regulated working conditions, and formal recognition of agricultural work. Without legal inclusion under the labour law, workplace heat stress standards cannot be formally applied, nor can effective inspection, compliance, and enforcement mechanisms be ensured within the agricultural sector.

The adaptations needed could draw from the dedicated OSH guide tailored to the agricultural sector that has been developed jointly by the ILO and the Ministry of Agriculture.[27] The guide was developed based on the Preliminary Assessment of OSH in the Agriculture Sector in Lebanon[28] and includes a specific section on workplace heat stress prevention, with practical recommendations adapted to the working conditions and exposure patterns typical of agricultural labour. To ensure that these measures are consistently and effectively implemented, the guide could be formally adopted and rendered legally enforceable under the authority of the Ministry of Labour. Such formalisation would enable the systematic application of workplace heat stress prevention protocols, alongside broader OSH requirements, across the agricultural sector.

The development of effective, sector-based adaptation plans for agriculture could begin with targeted awareness-raising and training for both workers and employers. These initiatives could communicate the benefits of applying OSH standards and legal protections, while clearly outlining the risks associated with non-compliance, including accidents and health outcomes associated with workplace heat stress. Training programmes could cover the recognition of workplace heat stress symptoms, clarify the respective responsibilities of employers and workers, and provide practical guidance on safe work practices during periods of high or extreme heat.

Risk reduction may also benefit from a clear definition of roles and responsibilities, emphasising that proper implementation of OSH standards helps limit employer liability while enabling workers to assert their right to safe and healthy working conditions. Sectoral adaptation plans could ensure that all agricultural workers receive equal protection, irrespective of recruitment arrangements or employment status, including workers engaged informally or through intermediaries. This entails guaranteeing access to workplace heat stress prevention measures, accident insurance, and OSH-related information and training across the sector.

Encouraging the registration of farms and workers in the Agricultural Registry could support both implementation and enforcement. Registration facilitates access to employers for training and inspection purposes, while enabling workers to benefit from OSH guidance, workplace heat stress regulations, and social protection measures. As agricultural registration increasingly enables access to public support and investment grants, formal inclusion of agriculture under the Labour Law would ensure that registered agricultural employers fall under the oversight of the Ministry of Labour and are subject to labour law obligations, including compliance with OSH and workplace heat stress requirements.

Strengthening integration further would require linking OSH enforcement, including workplace heat stress prevention measures, to existing social protection systems, notably the National Social Security Fund. Ensuring the mandatory application of OSH protections to all agricultural workers, including those in informal employment who are currently not covered by the National Social Security Fund, would support achieving comprehensive protection. Aligning labour law coverage, OSH enforcement, and social protection mechanisms would substantially enhance the effectiveness and equity of workplace heat stress risk management in agriculture.

Expanding and supporting labour inspection and data systems in agriculture would require bringing agricultural workplaces under formal regulatory oversight. Including agricultural workers within the scope of the labour law, together with making farm registration compulsory, would provide labour inspectors with formal access to agricultural worksites and the legal authority to enforce OSH requirements, including workplace heat stress standards. Registration would also ensure that both employers and workers fall under the authority of the Ministry of Agriculture and within the jurisdiction of the labour law, thereby improving their visibility within inspection, monitoring, and data-collection systems, including those operating in informal or semi-informal contexts.

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[27] https://www.ilo.org/resource/news/ilo-launches-first-occupational-safety-and-health-guide-agriculture-lebanon

[28] ILO (2023). Preliminary assessment of occupational safety and health in the agriculture sector in Lebanon, Geneva: International Labour Office.

In parallel, inspection and protection mechanisms could be explicitly extended to vulnerable groups within the agricultural workforce, including displaced persons, seasonal workers, and workers recruited informally. Ensuring that these groups are systematically included in data-collection mechanisms, covered by labour inspection activities, and fully protected by OSH and workplace heat stress regulations would support achieving comprehensive and equitable risk management across the agricultural 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.

Integrating workplace heat stress prevention into the OSH framework for the construction sector could include, as an initial step, clarifying and strengthening the legal provisions applicable to construction workers. Ensuring that construction workers are unequivocally covered under the labour law is essential, as existing legal ambiguities constrain the effective enforcement of workplace heat stress standards and broader OSH requirements on construction sites. Clear legal coverage is, therefore, a prerequisite for embedding workplace heat stress prevention obligations within the national OSH framework.

At the same time, effective implementation would be supported by clear definition of roles and responsibilities among key duty holders. This involves having have explicitly defined obligations for employers, contractors, and site supervisors with respect to OSH compliance, including the implementation of workplace heat stress prevention measures such as access to cooling and shaded areas, hydration policies, and the adjustment of work schedules during periods of high or extreme heat.

Robust state oversight will ensure effective integration of workplace heat stress prevention into the OSH framework. Strengthening government monitoring and labour inspection mechanisms will support the systematic application of workplace heat stress standards across construction sites, while the consistent application of penalties and sanctions for non-compliance will enhance accountability and reinforce adherence to OSH requirements.

Lebanon is encouraged to explicitly integrate workplace heat stress as an indicator within site-specific risk assessments conducted for construction projects. Incorporating workplace heat stress risk into these assessments would enable engineers and safety professionals to systematically identify high-risk tasks and locations, thereby informing decisions on where cooling infrastructure, shaded work areas, hydration stations, and adjusted work-rest cycles are most urgently required.

Effective adaptation also depends on the availability of adequate resources to support implementation. Construction sites and labour inspection services should be equipped with the necessary tools, equipment, materials, and staffing to apply workplace heat stress prevention and mitigation measures in practice. Strengthening institutional capacity is needed, which can be supported by digital and artificial intelligence-based tools for workplace heat stress risk assessment, monitoring, and enforcement.

Coordinated planning and implementation among relevant ministries, public agencies, and trade unions is key. Such coordination is essential to ensure consistency and coherence in the rollout of workplace heat stress measures and broader OSH practices across the construction sector, and to avoid fragmented or uneven application.

Strengthening job security is another key enabling factor for safer working environments in the Lebanese construction sector. Stable and well-protected workers are more likely to comply with OSH procedures, participate in training, and report unsafe conditions without fear of retaliation. Building workers' capacities through structured awareness programmes, practical training, and emergency drills is, therefore, critical. These measures support improved understanding of workplace heat stress risks, early recognition of symptoms, and adherence to safe work practices during heatwaves, and should form a core component of construction-sector adaptation plans.

Enhanced state oversight is necessary to establish a systematic approach to monitoring heat exposure and to support the collection of reliable data across both formal and informal construction workplaces. Strengthening labour inspection and data systems for monitoring workplace heat stress risk in the construction sector requires reinforcing both the capacity and effectiveness of inspection mechanisms, including the need for adequate incentives, transportation, and appropriate tools and equipment to enable inspectors to conduct site visits effectively. Active, technically informed labour inspection, supported by regular site visits and engineering-based assessments, is essential to ensure that inspection activities can be carried out consistently and at sufficient scale for identifying workplace heat stress related hazards and ensuring compliance with OSH requirements on construction sites.

Improved coordination among relevant ministries, labour authorities, and trade unions is a further priority. Strengthened coordination will facilitate information sharing, harmonisation of inspection procedures, and consistent application of workplace heat stress regulations across the construction sector. Applying clear and enforceable penalties and sanctions to employers or contractors that fail to meet OSH obligations, thereby creating a meaningful deterrent to non-compliance, is key to reinforce compliance.

Finally, there is a need for accessible mechanisms that allow workers to report workplace heat stress risks and unsafe conditions. Such reporting systems, combined with strengthened inspection services, will help ensure that all workers, including those in informal or temporary employment, are covered by inspection activities and included in national data systems. In this process, ensuring confidentiality in reporting processes will encourage worker participation and reduce fear of retaliation.

Manufacturing: Manufacturing facilities, whether operating indoors or in partially exposed environments, should be encouraged to address both process-generated and environmental heat. Enhancing indoor climate control through improved ventilation and energy-efficient air conditioning systems should be 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.

Updating existing standards, or developing additional ones, under the authority of the Lebanese Standards Institution (LIBNOR) would support integrating workplace heat stress prevention into the national OSH framework for the industrial and manufacturing sectors. Incorporating heat-specific technical requirements into relevant sectoral standards is key, as working conditions, production processes, and patterns of heat exposure vary substantially across industrial activities. Reflecting these differences through sector-specific provisions would allow the OSH framework to accommodate varying implementation needs while ensuring adequate protection against heat-related risks.

To support this process, the Lebanese Standards Institution could establish a dedicated technical committee composed of experts from multiple industrial sectors. Such a committee could facilitate the systematic review and updating of standards by ensuring that diverse industrial environments and workplace heat stress risk profiles are adequately considered. A cross-sectoral technical body would also help harmonise approaches, identify gaps in existing standards, and develop coherent guidance that can be integrated into the national OSH system, thereby strengthening the regulatory foundation for workplace heat stress prevention in the context of increasing climatic risks.

Establishing clear timelines for planning and implementation would support the development of adaptation plans for managing workplace heat stress in the industrial and manufacturing sectors. Setting realistic yet firm deadlines for enterprises to comply with new workplace heat stress standards and broader OSH requirements is key, to support orderly transition while ensuring timely risk reduction.

Employer incentives are a critical enabling factor. Incentive mechanisms can encourage early adoption of workplace heat stress prevention measures and help offset the costs associated with installing cooling systems, adapting work environments, or modifying production schedules. Adaptation planning should further ensure that adjustments to working hours and work-rest arrangements reflect the specific determinants of heat exposure in industrial settings, including machinery-generated heat, inadequate ventilation, and confined indoor spaces. Sector-specific and location-specific considerations, such as facilities operating in dense residential areas, should, therefore, guide the design of protective measures and work organisation strategies.

Comprehensive training and awareness-raising for both workers and employers are essential to the effectiveness of any industrial workplace heat stress adaptation plan. Industrial workers should be educated and trained to understand workplace heat stress risks, recognise early symptoms, and follow safe work practices, while employers and managers need clear guidance on their responsibilities and on the operational adjustments required to reduce heat exposure. This shared awareness and engagement, across both the workforce and management, is a prerequisite for the successful and sustained implementation of workplace heat stress prevention measures in industry and manufacturing.

Strengthening labour inspection and data systems in the industrial and manufacturing sectors requires a more decentralised approach to inspection and oversight, allowing responsibilities to be distributed across regions and better aligned with the characteristics of local industrial zones. Decentralisation may enhance the ability of inspection services to monitor diverse workplaces effectively, including small and medium-sized enterprises, which are often particularly vulnerable to workplace heat stress risk.

Clear definition of roles and responsibilities is essential to improving inspection and monitoring systems. Strengthened coordination and communication among relevant institutions, including ministries, local authorities, the Lebanese Standards Institution, trade unions, and employers' associations, would support the alignment of inspection priorities, harmonisation of data-collection processes, and avoidance of duplication across agencies.

Finally, effective monitoring of workplace heat stress in industrial settings should be linked to broader urban planning and sustainable development strategies. Industrial zones frequently intensify heat exposure due to dense built environments, limited green space, and heat generated by machinery and production processes. Integrating workplace heat stress prevention considerations into local development and planning frameworks would, therefore, help reduce exposure at the source and support safer and more sustainable working conditions across the sector.

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 heat waves will protect both 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 Lebanon, as demonstrated in this study. This agenda aims to provide safe, productive, and fair working conditions, which are increasingly critical as Lebanon faces heightened climate impacts, particularly rising heat stress levels. As shown below, by aligning its climate adaptation and OSH measures with the Decent Work Agenda, Lebanon can foster resilience in its labour market, prioritizing the well-being and safety of its workforce.

- **Promoting Safe and Healthy Workplaces in Lebanon Amidst Rising Heat:** The Decent Work Agenda[29] emphasizes safe and healthy workplaces as a foundation for sustainable and fair employment. For Lebanon, integrating OSH conventions, such as Convention No. 155 (Occupational Safety and Health) and Convention No. 161 (Occupational Health Services), provides a pathway for protecting workers in sectors exposed to extreme heat, particularly in its agriculture and construction sectors. As shown in the present study, these sectors are vital to Lebanon's economy yet are highly vulnerable to climate impacts, making workplace protections for heat stress an urgent priority. Implementing national heat stress guidelines and mandatory heat mitigation strategies aligns with the Decent Work Agenda's goal of ensuring safe working conditions across industries.[29]

- **Enhancing Productivity through Climate-Responsive OSH Measures:** Safe working conditions are integral to worker productivity, a key focus of the Decent Work Agenda.[29] By establishing heat adaptation measures, such as work-rest cycles and hydration protocols, Lebanon can reduce productivity losses caused by heat stress.[1] These measures help maintain productivity during peak heat stress periods, mitigating economic disruptions and fostering a resilient labour market.[1] The Agenda's commitment to fair and productive workplaces underscores the importance of addressing environmental risks that can undermine economic stability and workforce productivity.[29]

- **Focusing on Vulnerable and Informal Workers:** Informal workers, often in agriculture, construction, and other high-risk sectors, are particularly vulnerable to climate impacts due to limited access to social protections and occupational safety measures.[1] The Decent Work Agenda emphasizes inclusive and equitable working conditions, which include protections for vulnerable groups.[29] Implementing OSH standards in response to climate risks ensures that these workers are not disproportionately affected by rising heat. By mandating workplace protections, Lebanon can address both climate resilience and social equity, creating safer working environments for all segments of its labour market.

- **Advancing Social Protection and Fair Conditions:** The Decent Work Agenda highlights social protection as a pillar of fair and sustainable employment.[29] Lebanon's adoption of ILO OSH Conventions can support the development of social protections that are climate-responsive, offering services such as health monitoring, emergency response, and compensation for heat-related illnesses. This approach ensures fair conditions in the face of climate change, aligning with the Agenda's vision of just, secure employment for workers impacted by environmental stressors.[29]

- **Contributing to Lebanon's Just Transition to a Climate-Resilient Economy:** Integrating the Decent Work Agenda into climate adaptation efforts also aligns with Convention No. 187 (Promotional Framework for OSH), which supports ongoing improvements in national OSH policies. This framework is instrumental for Lebanon's just transition, helping the country build a climate-resilient economy by fostering fair and sustainable working conditions across sectors. By embedding OSH standards in

[29] 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).

climate policies, Lebanon can protect its workforce, ensuring that all workers, particularly those in high-risk sectors, are supported from the impacts of climate change and rising heat stress.

Taken together, the above showcases how, aligning climate adaptation measures with the ILO Decent Work Agenda offers Lebanon a comprehensive approach to addressing climate impacts on labour, ensuring that the workforce remains safe, productive, and resilient amidst rising heat.

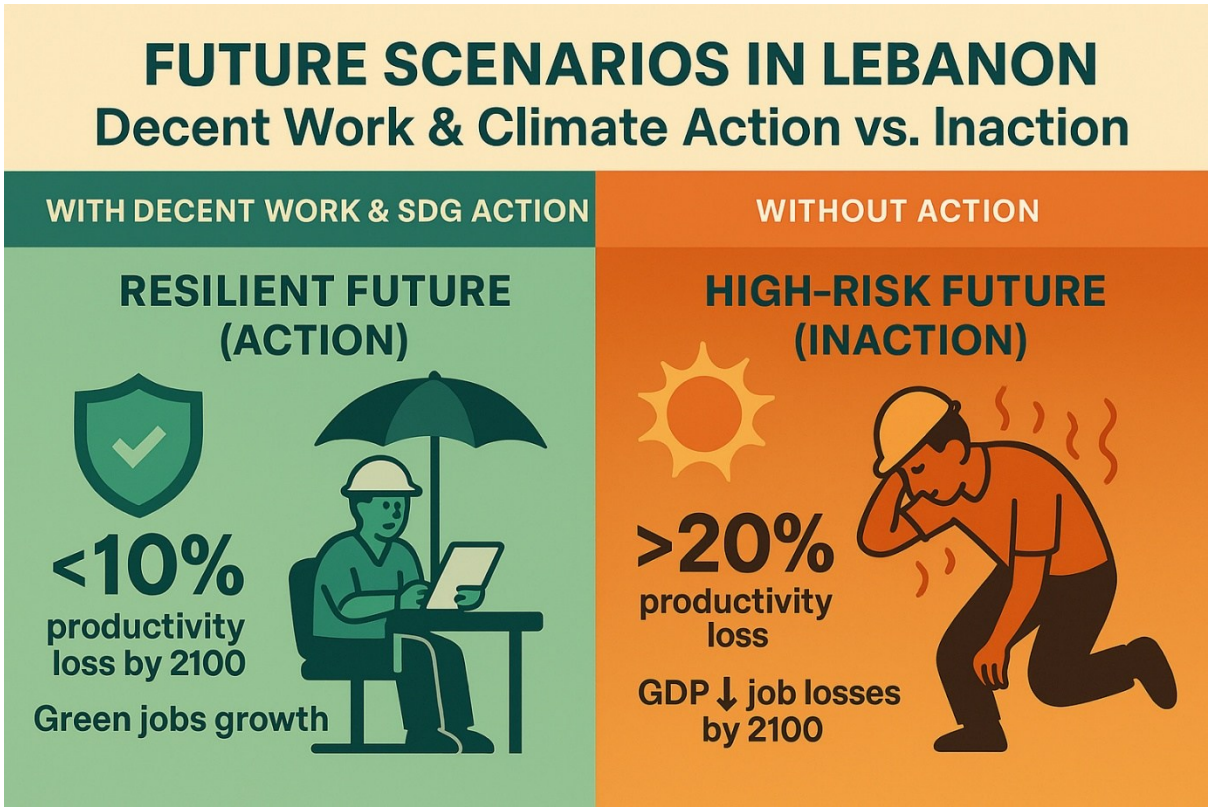
7. Scenario analysis to decent work and SDG implementation

Building on the findings described in Sections 2-5, scenario analyses were used to illustrate the potential economic and social impacts of implementing ILO's Decent Work Agenda and the 2030 Agenda for Sustainable Development in Lebanon. This analysis compares futures where these agendas are fully embraced versus not, in the context of climate change. Two contrasting scenarios can be outlined (key results summarized in Infographics 1-2):

- **Scenario 1: "Sustainable Decent Work Future"** – *High ambition for climate and decent work.* In this scenario, Lebanon implements comprehensive policies in line with the ILO's Decent Work Agenda *and* the Sustainable Development Goals. This means aggressive climate action and adaptation measures, along with social and labor reforms:

  - **Climate Pathway:** Global and national efforts limit climate change, in line with SSP1-2.6 or Paris Agreement goals. Temperature and heat stress increases are kept moderate.
  - **Policy Actions:** The country invests in adaptation and labour protections. For example, authorities enforce heat stress management in workplaces (see Section 6), extend social protection floors to cover workers affected by climate shocks, promote green jobs in renewable energy and climate-resilient infrastructure, and strengthen social dialogue so that workers' voices shape adaptation strategies. These actions reflect core Decent Work pillars (employment, social protection, rights, social dialogue) directed at climate resilience.
  - **Impacts:** With lower global warming and strong domestic measures, the negative impacts on productivity and jobs are greatly mitigated. The findings presented in Section 3.2.2 show that, under a low-emissions scenario, productivity loss due to rising heat stress from climate change is relatively limited (only **2-10% loss** in low/moderate-intensity work and **8-10% loss** in high-intensity work by 2100). If Lebanon further improves workplace conditions by adopting effective labour policies (e.g. those outlined in Section 6), even these modest losses can be curbed. Economically, this scenario means **far less GDP lost** to heat stress. For instance, whereas 2023 saw an estimated **USD 326 million GDP loss due to climate-induced heat stress**, under a sustainable path this annual loss would grow slowly or even plateau as adaptation is initiated. Socially, the number of jobs at risk would be much lower: the estimate of **~10,000 full-time equivalent jobs lost** (see Section 5.3) to heat stress would remain manageable or decline with interventions. In short, this "high-action" scenario portrays a Lebanon that achieves **resilient growth** – protecting workers from climate hazards, creating new decent jobs in sustainable industries, and thus advancing multiple Sustainable Development Goals (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.

Infographic 1. Scenario analysis to decent work and sustainable development goal implementation. Figures calculated based on the results presented in Section 5.



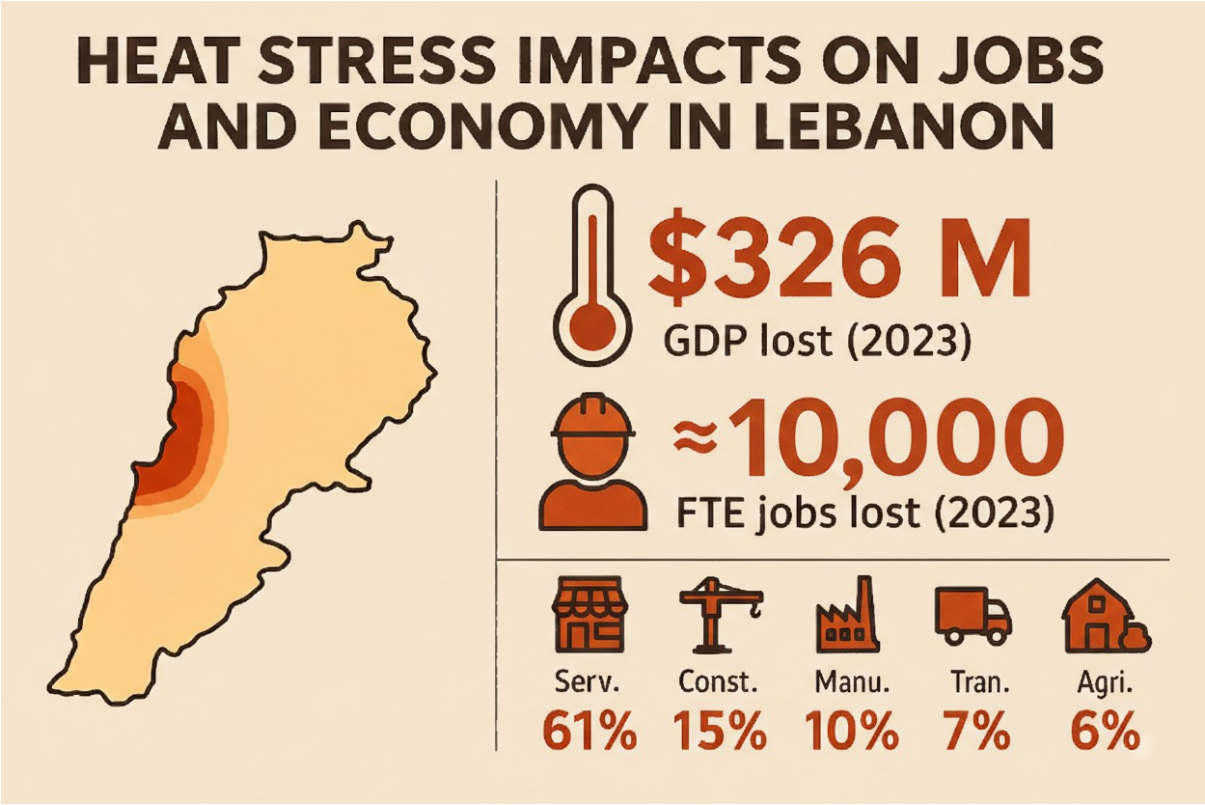
- **Scenario 2: "Business-as-Usual and Inaction"** – *Low ambition, high climate risk.* This scenario assumes that neither strong climate action nor Decent Work Agenda reforms are pursued sufficiently:

  - **Climate Pathway:** The world follows a high-emissions trajectory (analogous to SSP5-8.5), leading to **severe warming** and intensifying heat stress in Lebanon. By late century, summers are significantly hotter – a drastic rise in days exceeding safe work temperatures.
  - **Policy Status:** Lebanon's policies remain reactive or fragmented. Workplace safety measures against heat are minimal, social protection systems do not expand to cover climate-related risks (leaving many informal and rural workers without support), and opportunities in the green economy are missed. Economic development continues with a brown growth model (economic development that relies heavily on fossil fuels and does not consider the negative side effects that economic production and consumption have on the environment), and labour rights/enforcement improvements stall.
  - **Impacts:** Under this scenario, the **worst case** from the present analysis **comes true**. By 2100, workplace productivity in high-intensity labour could **decline by over 22%** due to extreme heat, and even low-intensity sectors will see 10-15% drops. The loss of workable hours would slash national output – effectively, climate change becomes a major burden on GDP. In 2023, climate-induced heat stress already cost 1.03% of GDP; by mid-to-late century under unabated warming, Lebanon could be losing several percentage points of GDP annually from heat stress alone. The sectoral breakdown of productivity indicates the **agriculture and construction sectors** would be hardest hit, potentially facing productivity losses up to ~32% in worst conditions by 2100 (loss observed during historical period plus loss caused by climate change), which is devastating for livelihoods in rural communities and among outdoor workers. In terms of employment, the **FTE job losses would mount year by year**. Today's ~10,000 annual jobs

lost could increase many-fold as temperatures rise – meaning tens of thousands of jobs effectively erased by climate impacts. Unchecked, this scenario undermines several Sustainable Development Goals: poverty and inequality worsen (as vulnerable workers lose income), health deteriorates (from heat-related illnesses), and economic growth stalls (missing targets of Goal 8). Moreover, without decent work reforms (Section 6), any new jobs that do appear (e.g. in adapting infrastructure) may be low-quality or informal. This Business-as-Usual scenario paints a grim picture of **social and economic strain**, illustrating the high cost of inaction. It reinforces the rationale behind ILO's call for a just transition – without proactive policies, the **"high-emission, no-reform" pathway** leaves the workforce exposed to climate shocks and foregoes the benefits of sustainable development.

In the above scenarios the difference is stark: one future where Lebanon's economy is more resilient, diversified with green jobs, and workers are protected – versus another future where climate change inflicts heavy losses and development goals slip out of reach. Importantly, there is a gradient between these extremes. For instance, an intermediate scenario might have moderate climate action and partial policy uptake, yielding mixed outcomes. Another scenario of **"delayed action"** may also materialize, where warming continues unchecked until mid-century, then belated policies are implemented. Projections for such a scenario suggest that, while late mitigation/adaptation is better than none, some losses (economic damages, depleted worker capacity) become irreversible.

Infographic 2. Economic and labour market impacts in Lebanon from climate-induced rising heat stress. Figures calculated based on the results presented in Section 5.



Implementation priorities

To realise Scenario 1, three enablers are pivotal. First, **embedding WBGT-based heat standards** into OSH regulation and public procurement, supported by labour inspection and worker participation. Second, **extending social-protection floors** to cover heat-related contingencies for formal and informal workers, with

simple triggers (e.g., WBGT thresholds) and rapid disbursement. Third, directing **public and concessional finance** towards efficient cooling, shade, hydration, and ventilation in SMEs and public facilities, urban heat mitigation, and climate-smart agriculture. At the same time, implementing **awareness raising campaigns** on the need to address workplace heat stress is key to ensure the private sector is informed about the benefits of adaptation actions on productivity and economic competitiveness. Monitoring should use Section 5 metrics as a baseline (GDP safeguarded, FTE jobs preserved, days above WBGT thresholds) and be reported through the Decent Work Country Programme. These and other necessary activities are outlined in Infographic 3.

A suggested timeline to implement the recommendations stemming from this study is presented in Infographic 3. Realizing the above roadmap within a short timeframe can be challenging because it requires the contribution of several stakeholders within the government. It is proposed, therefore, to form a **cross-ministerial group** that oversees the implementation of the roadmap. Proposed ministries include the Ministry of Labour, the Ministry of Health, the Ministry of Environment, the Ministry of Industry, the Ministry of Agriculture, as well as other relevant sectoral ministries as needed.

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

Infographic 3. 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 Lebanon'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.[22] This function was derived from field studies across various countries (including some in the Middle East) and is calibrated for an "average, experienced, acclimatized worker" operating under typical conditions.[22] While this provides a robust general framework, it may not capture all nuances of Lebanese labour contexts. For instance, actual work-rest behaviours, acclimatization levels, and protective measures in Lebanon 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.[16] 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 Lebanon. 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**. Lebanon's complex terrain and microclimates – from cooler higher altitude areas to hotter, humid coastal cities – may not be fully captured by grid-averaged climate data. Small geographic "hotspots" (for example, inner-city districts with urban heat island effects or particular valleys with extreme conditions) could, therefore, be under-represented. Similarly, using national or gridded averages for labour and economic activity can mask differences in heat exposure within sectors or regions. The model distributes impacts based on generalized population and sector data rather than detailed local employment patterns, so the **spatial distribution of losses** should be viewed as indicative rather than exact. Furthermore, there are **coverage gaps in labour data**, especially regarding informal employment. Official statistics and economic output data likely undercount informal and unregistered workers, who make up significant proportion of Lebanon'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 Lebanon. In reality, Lebanon's future emissions and development path may not neatly correspond to any single SSP. Lebanon'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 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 the Eastern Mediterranean. By using one model, the analysis assumes its simulation is representative, but if that

model underestimates (or overestimates) future heat extremes in Lebanon, 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 Lebanon 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 Lebanese 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 Lebanon'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, Lebanese 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 **individual and subgroup differences** are not captured – 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 might understate losses for the hardest-hit days. While the current study presents 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 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 Lebanese 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 Lebanon vary widely. Some offices or facilities are air-conditioned (keeping WBGT lower than outdoor), while in other workplaces without cooling, heat can build up more than the model's simple ratio may predict (especially during power outages or in poorly ventilated spaces). Likewise, **underground or enclosed worksites** (e.g. any mining or tunnel operations) were approximated from surface weather data, which may not fully reflect actual thermal conditions underground where geothermal heat and ventilation play a role. The exposure assumptions also treat entire sectors uniformly in terms of work setting. For example, the agriculture and construction sectors were considered mostly outdoors (hence directly exposed to ambient heat), whereas sectors such as services or manufacturing were treated as predominantly indoor. In a Lebanese context, this generalized approach may be an oversimplification. Within services, a tourism worker guiding tours outside faces different heat stress than a bank employee inside an air-conditioned branch, yet both are counted under "services." Even within outdoor sectors, micro-environmental differences (working in shade versus sun, use of protective clothing, etc.) are not distinguished. Consequently, the **sector-level results should be interpreted as averages**, as actual heat exposure and productivity loss can vary within a sector based on specific job roles and locales. Moreover, because the analysis aligns workers with grid-cell climate data (using population distributions and national economic data), any mismatch between where people live versus where they work could introduce minor errors. For example, if many workers commute from cooler highlands to hotter coastal workplaces, the model may underestimate their exposure by tying them to home location climate. These granular issues are inherent in a

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

In conclusion, while the present study's projections of climate-induced workplace heat stress impacts on jobs and productivity in Lebanon 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 Lebanon'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 Lebanon'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[30] was adopted because it is considered the most accurate method when calculating WBGT from meteorological data.[31] 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.[32] Solar radiation was estimated[33] 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.[34] 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.[31] Indoor temperature and humidity were estimated as a function of outdoor conditions.[35] Similarly, for the mining industry, underground temperature[36] and humidity[37] 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,[38] covering the years 1990, 1995, 2000, and 2005, was obtained at a 15 arc-minute resolution. This dataset was already aligned with the target resolution and contained important information related to grid cells, including country mapping and land-water areas and it was used as the reference dataset for subsequent analysis.

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Population projections datasets, based on the SSP1, SSP2, SSP3, SSP4, and SSP5 were obtained from standard sources.[39,40] 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.[41] 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[42] 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,[43] 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.[44,45,46] 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.[47] 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)[48] 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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[42] GEBCO Bathymetric Compilation Group. The GEBCO_2023 Grid - a continuous terrain model of the global oceans and land. 2023, NERC EDS British Oceanographic Data Centre NOC.
[43] Copernicus Climate Change Service (C3S). CMIP6 climate projections, in Climate Data Store (CDS). 2021.
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[48] Copernicus Climate Change Service (C3S). (2019). Land cover classification gridded maps from 1992 to present derived from satellite observation, in Climate Data Store (CDS).

the urban area cells using xarray's coarsen method.[49] 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[50] 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.[51] 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,[52] 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.[53]

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

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

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

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

[53] Wang, T., & Sun, F. (2023). Global gridded GDP under the historical and future scenarios [Data set]. Zenodo. https://doi.org/10.5281/zenodo.7898409.

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

A1.2.8. Employment Dataset

Economic activity data was obtained from ILOSTAT,[55] 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[56] 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.[57] 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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[55] International Labour Organization (ILO). Employment by sex and economic activity -- ILO modelled estimates, Nov. 2023 (thousands) -- Annual, in ILO Modelled Estimates (ILOEST) Database. 2023, ILO, Geneva, Switzerland.
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