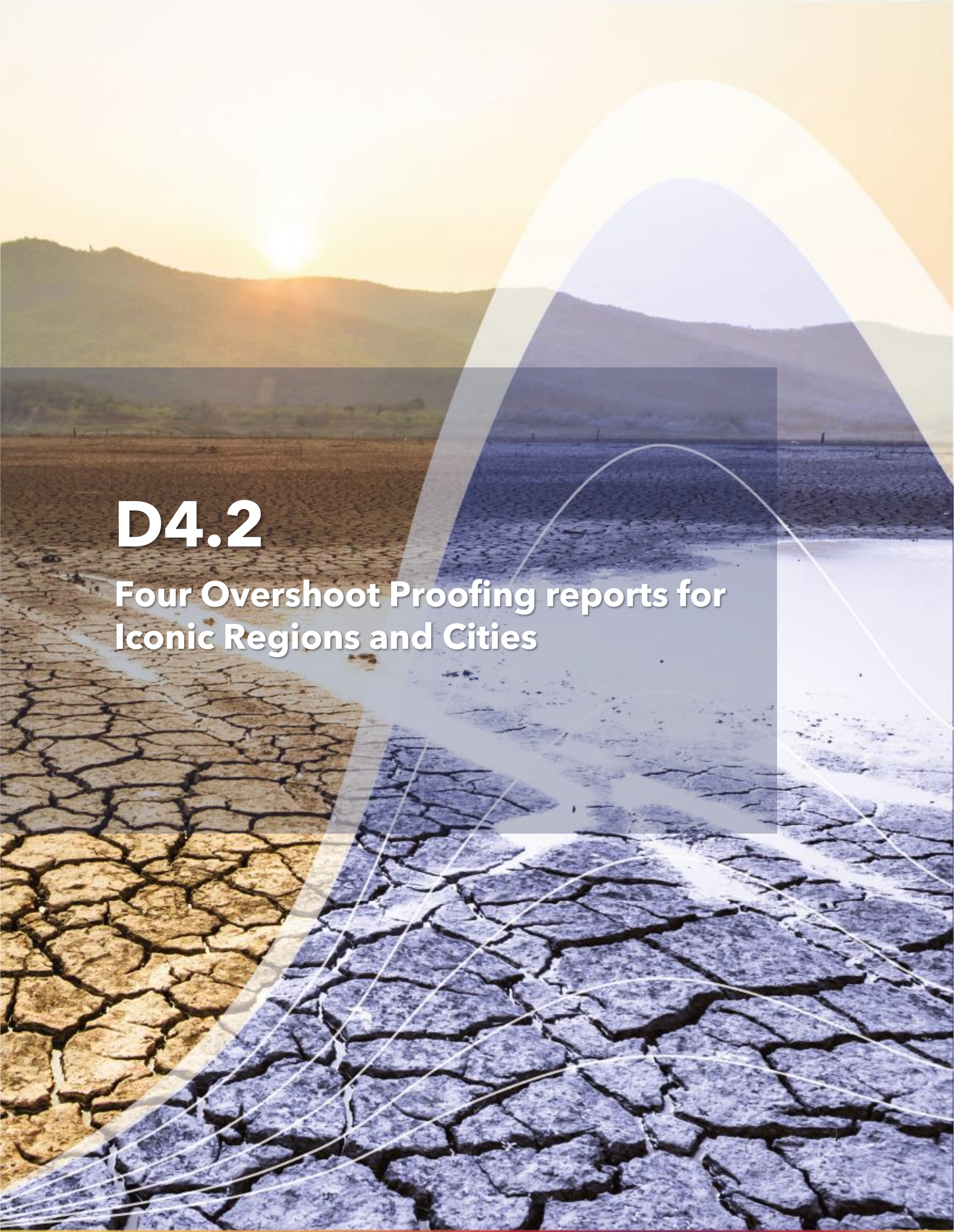

D4.2

Four Overshoot Proofing reports for Iconic Regions and Cities

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D4.2 Four Overshoot Proofing reports for Iconic Regions and Cities

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Table of contents

List of Figures **5**
Executive Summary **11**
1. Introduction **12**
1.1. Purpose of PROVIDE 12
1.2. WP4 – Iconic Regions and Cities 13
1.3. Importance of this report to local adaptation planning 15
1.4. The Overshoot Proofing Methodology and its implications 16
1.5. Modelling framework applied 17
1.5.1. Flood4cast 17
1.5.2. UrbClim 17
1.5.3. UBCWM 19
1.5.4. CLIMADA 20
1.6. Links between the modelling and engagement activities 20
2. Arctic Fennoscandia and Bodø municipality, Norway **22**
2.1. Context and reference 22
2.2. Modelling approach to overshoot and adaptation 23
2.2.1. Data and model setup 23
2.2.2. Results from the modelling 25
2.3. Spatial challenges and opportunities for overshoot adaptation 27
2.4. Overshoot Proofing and stakeholder co-development Process 28
2.5. Reflections on the co-development process 32
3. Iberian Mediterranean and Lisbon Metropolitan Area, Portugal **33**
3.1. Context and reference 33
3.2. Modelling approach to overshoot and adaptation 35
3.2.1. Urban Heat Stress Assessment using UrbClim model: Lisbon Metropolitan Area 35
3.2.2. Urban Heat Impact Assessment using CLIMADA model: Lisbon Metropolitan Area 40
3.3. Spatial challenges and opportunities to overshoot adaptation 43
3.4. Overshoot Proofing and stakeholder co-development process 46
3.4.1. Overshoot Proofing Application 46
3.4.2. Results 48
3.5. Reflections on the co-development process 53
4. Upper Indus Basin and Islamabad, Pakistan **54**
4.1. Context and reference 54
4.2. Modelling approach to overshoot and adaptation 56
4.2.1. Urban Heat Stress Assessment using UrbClim model: Islamabad 56

4.2.2. Spatial Capacity Analysis for Adaptation to Heat Stress: Islamabad 59
4.2.3. Urban Heat Impact Assessment using CLIMADA model: Islamabad 61
4.2.4. Coupling of UBCWM with Open Global Glacier Model (OGGM): Projected Streamflow in the Upper Indus Basin 64
4.3. Spatial challenges and opportunities to overshoot adaptation 66
4.4. Overshoot Proofing and stakeholder co-development process 69
4.4.1. Overshoot Proofing application 71
4.5. Reflections on the co-development process 76
5. Bahamas and Nassau, The Bahamas 77
5.1. Context and reference 77
5.2. Modelling approach to overshoot and adaptation 79
5.2.1. Urban heat stress assessment using the UrbClim model: Nassau 79
5.2.2. Urban Heat Impact Assessment using CLIMADA model: Nassau 80
5.3. Spatial challenges and opportunities to overshoot adaptation 82
5.4. Overshoot Proofing and stakeholder co-development process 84
5.4.1. Results 85
5.5. Reflections on the stakeholder co-development process 88
6. General discussion and conclusions 90
6.1. Implications for the PROVIDE Overshoot Proofing Methodology 90
6.1.1. Improvements to the Overshoot Proofing Methodology 90
6.2. Feedback on the usefulness of the PROVIDE Climate Risk Dashboard 91
6.3. Implications for further work in PROVIDE with the regional stakeholders 91
7. Bibliography 93
8. Annexes 96
8.1. Indicators calculated by UrbClim 96

List of Figures

Figure 1: PROVIDE is organized in interlinked work packages.. 13
Figure 2: Regions and cities in focus for PROVIDE 14
Figure 3: Overview of the applied UrbClim methodology 19
Figure 4: A schematic diagram of UBC watershed model 19
Figure 5: Delineation hydrological catchment Bodø.. 23
Figure 6: Surface layer (left) and urban layer (right).. 24
Figure 7: Flood prone areas in Bodø (NVE's flood caution map). Source: https://www.nve.no/map-services/ 24
Figure 8: Flood lines and critical points in Bodø 25
Figure 9: Flood map current climate storm with return period of 100 years (flood depth < 5cm are not shown) compared with the flood prone areas Norway................................ 26
Figure 10: Flood map future climate (2050) storm with return period of 100 years (flood depth < 5cm are not shown) 26
Figure 11: Potential green network for Bodø, with existing and potential green corridors and focus zones for a strategy of de-sealing of zones with a concentration of impermeable surfaces... 28
Figure 12: Night-time urban heat island intensity. Three areas are highlighted (1: Monsanto Parc, 2: Barreiro-Lavradio industrial area, 3: Lisbon city centre with an increased vegetation cover towards the north)... 36
Figure 13: Heat stress levels at 1 m spatial resolution for the city of Lisbon. Three insets with different urban morphology are shown 37
Figure 14: Temperature changes for Portugal with respect to pre-industrial temperatures for the scenarios of "Current Policies", "Delayed Action" and "1.5ºC – Shifting Pathways" coloured in light blue, dark blue and yellow, respectively. 37
Figure 15: Number of annual heatwave days in present times (2011-2020; left) and by mid-century projected under the different PROVIDE scenarios (high emission) (2041-2050; right)... 39
Figure 16: Left: Population exposure distribution for Lisbon at 100m resolution as provided by WorldPop for 2020 and divided in the NUTS3 administrative unit boundaries provided by the Portuguese government https://www.dgterritorio.gov.pt/dados-abertos. Right: impact function for the loss of minutes of sleep in function of the minimum daily

temperature. Note that negative values mean an increase in sleep with respect to the norm. Data taken from Minor et al. (2022) 40
Figure 17: Relative change in the heat-induced sleep loss (left) and heatwave affected people (right) impacts per decade with respect to the reference period 2011-2020 for the three emission scenarios “1.5ºC – Shifting Pathways”, “Current Policies”, and “Delayed Action” as provided by UrbClim (cf. Section 2.2.1). The x-axis represents the beginning of the following decade 41
Figure 18: Relative change in heat-induced sleep loss (left) and heatwave affected people (right) per parish for the decades 2041-2050 and 2091-2100 compared to the reference decade 2011-2020 for the three emission scenarios “Current policies”, “Delayed action” and “1.5 °C – Shifting Pathways”, as provided by UrbClim (cf. Section 2.2.21) 42
Figure 19: Spatial Adaptation Profile of the Lisbon Metropolitan Area for mitigation and/or adaptation to heat stress (BUUR PoS, 2023) 44
Figure 20: Spatial Adaptation Profile of the Municipality of Lisbon for mitigation and/or adaptation to heat stress (BUUR PoS, 2023) 45
Figure 21: Lisbon Metropolitan Area (in light orange) and the municipalities that participated in the Overshoot Proofing of their heat-related strategies or plans (in dark orange) 46
Figure 22: Average number of heatwave days in Islamabad (north) and Rawalpindi (south). Two insets are shown with their respective satellite images. The green square indicates the E-11 sector, for which a meter-scale analysis is executed 57
Figure 23: Heat stress levels at 1 m spatial resolution. Insets with different urban morphology are shown 58
Figure 24: Sources of heat stress experienced by humans within a city 58
Figure 25: Annual mean temperature in present times (2011-2020; left) and by mid-century projected under the CMIP6 SSP5.8-5 (high emission) scenario (2041-2050; right) 59
Figure 26: The study area within Islamabad’s green blue systems and the surroundings (left), and perspective view of pre-development drainage pattern (right) 59
Figure 27: Golra village in light yellow and the recent development of sector E-11 in white 60
Figure 28: Spatial land-use change (2002/2010/2022): in yellow the bare soil, in red the built-up area, in green the vegetation area and in blue the streams right of way (Year 2002) 61

Figure 29: Population exposure distribution for Islamabad and Rawalpindi at 100m resolution as provided by worldpop (left), and impact function for the loss of minutes of sleep-in function of the minimum daily temperature (right).. 62
Figure 30: Relative change in the heat-induced sleep loss (left) and heatwave affected people (right) impacts per decade with respect to the reference period 2011-2020 for the three emission scenarios: “1.5ºC – Shifting Pathways”, “Current Policies”, and “Delayed Action” as provided by Urbclim (c.f. Section 2.2.1). The x-axis represents the beginning of the following decade 63
Figure 31: Relative change in heat-induced sleep loss (left) and heatwave affected people (right) for the decades 2041-2050 and 2091-2100 compared to the reference decade 2011-2020 for the three emission scenarios “Current Policies”, “1.5ºC – Shifting Pathways” and “Delayed Action” as provided by Urbclim (c.f. Section 2.2.21) 64
Figure 32: Percentage change in streamflow predicted by UBCWM (input parameters fine-tuned with OGGM data) 66
Figure 33: Average daily heat stress levels at 1 m spatial resolution and details of zones set under a high heat stress 67
Figure 34: Natural waterways (streams right of way 2000) and the superimposed drainage system (2022) 68
Figure 35: Flood routing model and examples of flooded areas in sector E-11 68
Figure 36: Number of days per year in which very high heat stress (Wet Bulb Globe Temperatures exceeding 29.5°C) is experienced (top). A satellite image of the island is provided as a reference (bottom). 79
Figure 37: Number of heatwave days, defined as the number of days per year in which both daytime and nighttime temperatures are above the 90th percentile. 80
Figure 38: Asset distribution (left, top) and vulnerability impact function for asset damage (left, bottom). Population distribution (right, top) and vulnerability impact function for displacement (right, bottom) 81
Figure 39: Return periods up to 100 years for damaged assets (left) and displacement (right), for mid-century (top) and end-of-century (lower) for the overshoot scenarios Current policies, Delayed action and 1.5C Shifting pathways. As reference the risk curves for 2020 are indicated in red 82
Figure 40: Green-blue system of Nassau centre image by BUUR/PoS 2022 84

List of Tables

Table 1: Municipalities that participated in the Overshoot Proofing (plus the AML office) with indication of its area, total population and the strategy/plan that was selected for proofing 47

Table 2: Summary results from the application of the Overshoot Proofing Methodology in the AML Iconic City 49

Table 3: Selected General Circulation Models (GCMs) and scenarios 65

Table 4: Scorecard based assessment along with comments 74

Table 5: Overview of scores 88

List of Photos

Photo 1: Bodø, Norway © Helena Gonzales Lindberg 22

Photo 2: Workshop with stakeholders in Bodø Municipality at the Town Hall in Bodø. © Helena Gonzales Lindberg 29

Photo 3: Participants from the municipality and senior researcher Arild Gjersten from NRI and PROVIDE. © Helena Gonzales Lindberg 32

Photo 4: Lisbon Metropolitan Area, Portugal © Abílio Leitão 33

Photo 5: Facilitated workshop with AML adaptation practitioners at the Faculty of Sciences - University of Lisbon © Ricardo Encarnação Coelho 48

Photo 6: City of Islamabad, Pakistan © Hanan Khaleeq 54

Photo 7: Second stakeholder workshop in the Iconic City of Islamabad © Khadija Irfan. 70

Photo 8: Nassau, The Bahamas © Parsons Photography NL (CC BY-SA 4.0) 77

Glossary

CONCEPT	DESCRIPTION
Adaptation opportunities	Factors that make it easier to plan and implement adaptation actions, which expand adaptation options, or that provide ancillary co-benefits.
Adaptive capacity	The ability of systems, institutions, humans, and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences.
Iconic city	Cities and urban areas in each of the iconic regions addressed in the project, where vulnerability to various climatic risks have increased because of anthropogenic activity.
Iconic region	Region that is a representative example ("hotspot") of acknowledged distinctive regional features of climate change vulnerability.
Overshoot	Exceedance of risk/impact thresholds. Those can be in terms of global mean temperature increase related to the goals of the Paris Agreement, or (local) thresholds related to specific impacts or limits of adaptation actions.
Overshoot Proofing Methodology (OPM)	Indicator based assessment tool developed by PROVIDE consortium partners.
Temperature overshoot pathways/scenarios	Emission trajectories characterised by CDR deployment after achieving net-zero emissions, potentially enabling a subsequent decrease in global mean temperature.

ABBREVIATION/ ACRONYM	DESCRIPTION
AML	Lisbon Metropolitan Area
GBC	Green Building Code
IC	Iconic city
IR	Iconic region
OGGM	Open Global Glacier Model
OPM	Overshoot Proofing Methodology
SSP	Shared Socioeconomic Pathway
UBCWM	University of British Columbia's Watershed Model

Executive Summary

Knowledge of the risks and impacts under potential Paris Agreement overshoot scenarios is still incipient due to the lack of scientific information, incomplete understanding of the physical climate processes, and uncertainties in climate projections. Nonetheless, it is imperative that mitigation and adaptation efforts adopted today to decrease certain impacts and avoid critical losses and damages to society, systems and human lives, start taking such scenarios into account.

This report presents and discusses results from high-resolution modelling of climate change hazards, impacts and risks in four Iconic Cities (IC): (i) air temperature and thermal comfort in Lisbon, Portugal and Islamabad, Pakistan; (ii) flooding in Bodø, Norway; (iii) and cyclones in Nassau, The Bahamas. Moreover, it reports on the outcomes of the application of the PROVIDE project Overshoot Proofing Methodology (OPM), that was co-developed with stakeholders in these four case study locations.

Stakeholder interaction is considered an essential step in improving local adaptation planning under the PROVIDE framework. In addition to the OPM, the use of the PROVIDE Climate Risk Dashboard is meant to aid adaptation practitioners. Both tools can help to better understand and plan for expected impacts of overshoot scenarios at the regional level and to initiate the discussion about avoidance of critical thresholds at the local level.

The application of the OPM by PROVIDE partners together with stakeholders in all four ICs provide first steps towards resilient planning that accounts for overshoot scenarios in regions that present a high level of vulnerability to climatic changes. The application of the OPM to existing plans and policies during stakeholder workshops have reconfirmed a discernible gap in evaluating the potential ramifications of emerging climatic threats and their interplay with escalating vulnerabilities. It thus seems imperative to align policy formulation with scientific insights and further advance the discussion around discernible socio-ecological thresholds, irreversible impacts and adaptation limits.

However, the immediate integration of overshoot scenarios into resilience planning is challenging. One of our findings through extensive interaction with local stakeholders in Bodø, Lisbon, Islamabad and Nassau, is that one of the main aspects hindering immediate integration is the lack of local expertise, data, and the science-based approach that is central to OPM. Despite stakeholders contributing insights into the local contexts, impacts, vulnerabilities, and adaptation capacities, the incorporation of overshoot scenarios into adaptation planning requires a gradual approach.

While the high-level data modelling and scientific tools serves the purpose of informing and giving realistic outlooks of future scenarios to plan for, the stakeholder engagement grounds this knowledge both with local adaptation planners needs and, perhaps more importantly, their understanding of how planning for the future cannot go on business-as-usual. In the self-reflection and evaluation of their own policies and plans, the realisation of what specifically is at stake becomes more acute. Hopefully, this will improve local adaptation planning, strengthen local resilience, reduce vulnerabilities, and avoid maladaptation if overshoot scenarios occur.

1. Introduction

1.1. Purpose of PROVIDE

Overshooting the Paris Agreement and exceeding the global temperature goal of staying below 1.5°C is a distinct possibility (Brecha et al. 2022). The impacts of such overshooting at the local and global level can be particularly severe in the most vulnerable regions, systems, and in many sectors (e.g., social, ecological, Mendez et al. 2023; Sadai et al. 2022). However, planning for adaptation and mitigation strategies under overshoot scenarios can substantially reduce the threats in vulnerable regions. The PROVIDE project (Paris Agreement Overshooting – Reversibility, Climate Impacts and Adaptation Needs) addresses the challenges of considering impacts and adaptation needs under overshoot scenarios, from the global to the regional and local levels.

The specific objectives of this EU-funded project are to:

1) Produce global multi-scenario, multisectoral climate information which integrates and quantifies impacts across scales by means of novel climate and impact emulators.

2) Assess climate system uncertainties and feedbacks, and the (ir)reversibility of climate impacts to provide comprehensive risk assessments of overshooting.

3) Co-develop a generalisable overshoot proofing methodology for adaptation strategies to enhance adaptation action in response to overshoot risks.

4) Identify and prioritise overshoot adaptation needs in four highly complementary case study regions.

5) Integrate all project outcomes into a PROVIDE Climate Risk Dashboard.

The project is organized into seven Work Packages (WPs) - see overview in Figure 1 below - each one linked to the objectives presented above. The WP1 intends to understand the fundamentals of overshoot pathways, their global risks and components; WP2 will develop a global emulator of impact models for overshoot scenarios; WP3 will establish an Overshoot Proofing Methodology for enhancing adaptation decision making and policy; WP4 will apply urban adaptation planning under overshoot scenarios and overshoot proofing to Iconic regions and cities; WP5 provides a user-friendly tool with information on climate and climate impacts under overshoot trajectories, and WPs 6 and 7 focus on communication, dissemination and coordination of the project.

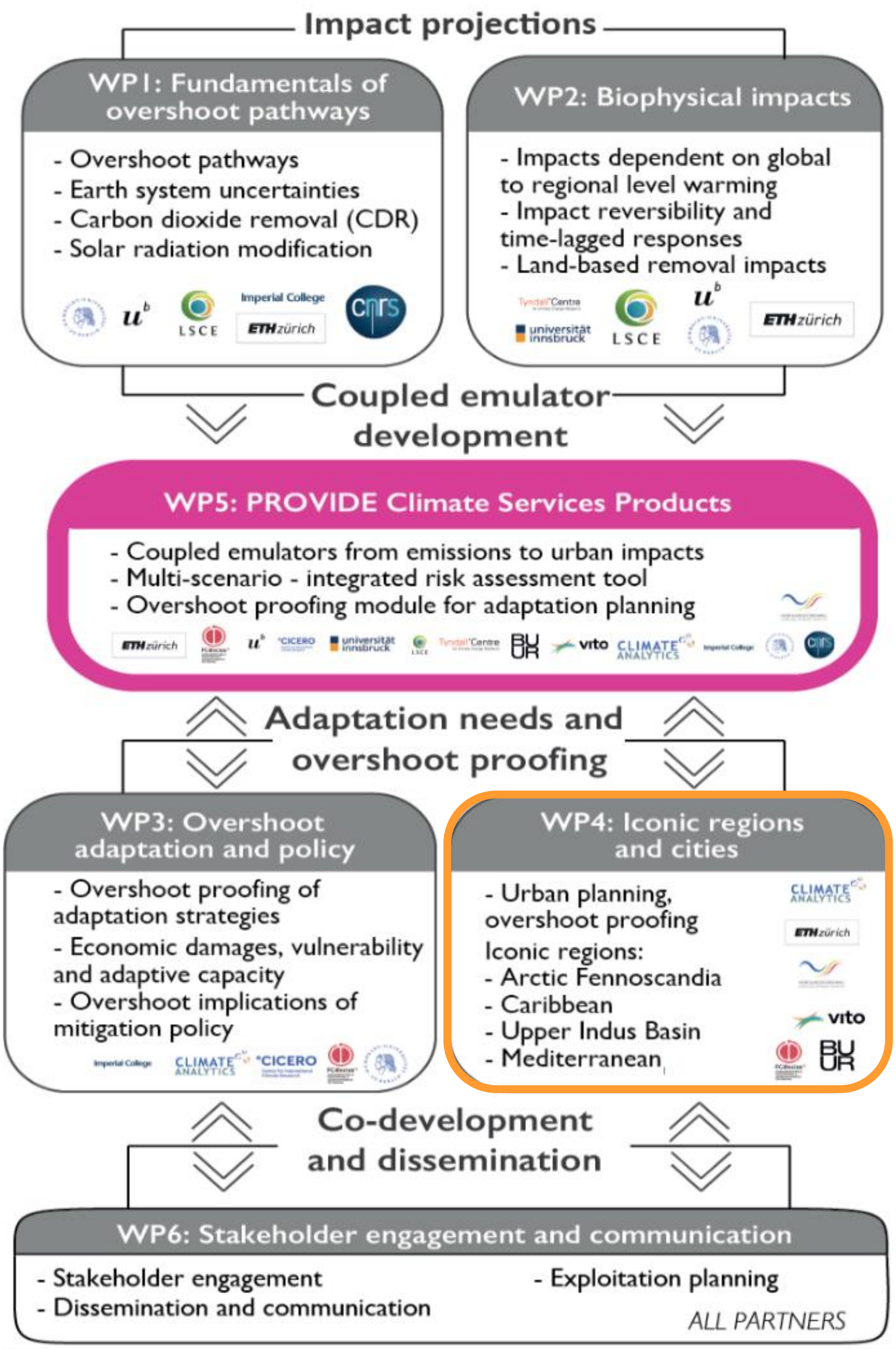

Figure 1: PROVIDE is organized in interlinked work packages

1.2. WP4 – Iconic Regions and Cities

The work developed under the Work Package4 focuses on the application of a common approach to analyse the overshoot adaptation strategies in four Iconic regions (IR) and one urban area, within each of these regions (Iconic cities – IC -; see Figure 2 on the following page).

These regions and cities are "Iconic" in the sense that they are representative examples ("hotspots") of acknowledged distinctive regional features of climate change vulnerability. The four regions are experiencing the consequences of climate change, including risks connected to more frequent and more serious severe weather events. The "iconic" in the description of the regions relates to the examples they bring forth:

Figure 2: Regions and cities in focus for PROVIDE

IR 1: Arctic Fennoscandia, with a focus on Bodø, Norway (Polar region)
The Arctic region is currently experiencing three to four times faster warming than the rest of the world. Arctic Fennoscandia is facing rapid warming with shorter and more unpredictable winters – which is a season that life is built around in the North. Including the lives of the many indigenous Sami populations.

IR 2: Iberian Mediterranean, with a focus on the Lisbon Metropolitan Area, Portugal (Desertification region)
The Iberian Mediterranean is a hotspot for climate change vulnerability, already experiencing extreme high temperatures, heatwaves, drought, desertification, and forest fires.

IR 3: The Upper Indus Basin, with a focus on Islamabad, Pakistan (Glacial mountain range region)
The Upper Indus Basin is one of the most populated areas in the world and is experiencing extreme situations of flooding due to glacial melt and heavy precipitation and flash flood events, and heatwaves already leading to human deaths. It is also the area of the highest number of glaciers outside the polar regions.

IR 4: The Bahamas, with a focus on Nassau, The Bahamas (Small island region)
Small developing island state with high vulnerability to sea level rise, increased intensity of tropical cyclones, and ocean acidification. The region is already extreme weather events that cause catastrophic damage and loss of lives and livelihoods. Very concentrated population on the capital island of New Providence.

There are significant similarities between the adaptation challenges faced by the iconic cities. In all four cities, vulnerability to various climatic risks have increased because of anthropogenic activity, such as the urbanization of coastal areas, construction leading to discontinuity of green-blue structures, and the intensity of the built-up space. All four places have possibilities to address their respective climatic risks, but they also face challenges related to a high degree of private land ownership along with governance regimes without sufficient coherence for the needs related to climate adaptation and mitigation.

The tasks and subtasks in WP4 (in total 3 tasks and 10 subtasks) are carried out in parallel in each of the four IR/IC. An initial stock-tacking of the regional and local climate risks and adaptation challenges in IR/IC was fulfilled in task 4.1 (see report of Deliverable 4.1). This report is based on literature reviews, mapping of the spatial structure profile of the ICs, and stakeholder consultations in each IR/IC. The following task 4.2 intends to identify and assess key risks, thresholds, and potential responses to overshoot pathways, by developing high-resolution modelling of impacts over each iconic city, and by engaging with the stakeholders at the local level.

Firstly, the report presents the results from the modelling of air temperature and thermal comfort in Lisbon and Islamabad, flooding in Bodø, and cyclones for Nassau. Secondly, it reports on the outcomes of the application of the OPM. The body of the report is organized into six chapters: Chapter 1 introduces the theme of the report and the PROVIDE project and the specificities of WP4 and task D4.2; Chapters 2 to 5 are dedicated to the results from each of the IR/IC; and Chapter 6 concludes a general discussion and way forward in the work package.

1.3. Importance of this report to local adaptation planning

Knowledge of the risks and impacts under potential Paris Agreement overshoot scenarios is still incipient due to the lack of scientific information, incomplete understanding of the physical climate processes, and uncertainties in climate projections. Nonetheless, it is imperative that mitigation and adaptation efforts are adopted today to decrease certain impacts and avoid critical losses and damages to society and systems, and therefore human lives.

However, the current modelling of overshoot and climate change scenarios typically occurs at the global scale and is therefore not suitable for adaptation planning at higher resolutions, such as at the regional and local scales. The results and conclusions retrieved from this report will supply the Iconic Regions and Cities with the tools and information necessary for regional and local adaptation planning to be more explicit in considering critical limits and thresholds to adaptation, and the projected risks of overshooting scenarios and trajectories.

In many regions of the world, mountain glaciers are important regulators of water availability and are also the second contributor to present day sea-level rise. They have a non-linear, time-lagged response to climate change (WCRP Global Sea Level Budget Group, 2018). Because of overshoot, meltwater from glaciers will increase or decline depending on their current dynamical state, before reaching net zero if glaciers vanish completely. For countries relying on water supply from these glaciers, expected changes in water availability under global warming situations might severely impact relevant adaptation planning on various sectors of the economy, livelihood, food security and ecosystem. To generate knowledge to strengthen informed decision making as per the local needs, glacial modelling approach under PROVIDE explicitly resolves runoff from regional glaciers (based on the Open Global Glacier Model, OGGM, model) to incorporate this potentially irreversible impact dimension into regional hydrological modelling (based on the University of British Columbia's Watershed Model, UBCWM) and the associated impacts further downstream for the Upper Indus Basin as a test case.

Heat stress in cities such as Islamabad and Lisbon occur when urban areas, with their dense infrastructure and limited green spaces, become significantly warmer than their surrounding rural areas due to various factors such as buildings absorbing and radiating heat, reduced vegetation, and the Urban Heat Island (UHI) effect. This escalating issue poses significant threats to the health, well-being, and overall liveability of urban dwellers. As temperatures soar and extreme heat events become more frequent and intense, understanding the causes, impacts, and potential mitigation strategies of heat stress in cities becomes essential for fostering resilient and sustainable urban environments.

Tropical cyclones are typical occurrences in The Bahamas, causing damage to physical assets and a high number of displaced people. Increasing impacts of cyclones due to higher frequency and intensity, alongside storm surges and coastal flooding, can represent a significant increase in risk for The Bahamas population, under future climatic conditions. Knowledge of local vulnerabilities under future overshoot can provide national adaptation plans with essential information to better delineate adaptation approaches.

The PROVIDE Climate Risk Dashboard is a user-friendly webtool designed to present the outcomes of the high-resolution modelling activities for future global warming scenarios. The webtool is under co-development between PROVIDE researchers and stakeholders, such as local adaptation practitioners and local policy makers. A first version of the Dashboard 0.1 was presented in October 2022, and its development has progressed based on the reviews and suggestions from the initial stakeholders' engagements in each IR/IC. These improvements allowed for a more developed version 1.0 to be presented in subsequential stakeholder engagements.

The presentation of the Climate Risk Dashboard, alongside the Overshoot Proofing Methodology (OPM) in each Iconic City, was considered an essential step to improve local adaptation planning under the PROVIDE framework. Usage of the Dashboard and the self-assessment tool presented in the OPM (see further explanation in section 1.4) intends to offer support to adaptation practitioners. Both tools can help to better understand and plan for expected impacts of overshoot scenarios at the regional level and to initiate the discussion about avoidance of critical thresholds at the local level. The use of the webtool PROVIDE Climate Risk Dashboard by stakeholders and its application within local adaptation planning will be the focus of the next phase in the PROVIDE project.

1.4. The Overshoot Proofing Methodology and its implications

The Overshoot Proofing Methodology (OPM) is a self-assessment tool that can be used by adaptation practitioners and stakeholders to evaluate how well their current adaptation policies and strategies take overshooting trajectories into account. The self-assessment is guided by a questionnaire to be filled by practitioners either independently or in conversation with PROVIDE researchers. The aim of this evaluation is to improve overall adaptation planning, strengthen local resilience, reduce vulnerabilities, and avoid maladaptation if overshoot scenarios occur.

The OPM questionnaire is organized into five sections (hereafter called categories): 1) Global warming scenarios of 1.5ºC, 2ºC and 3ºC; 2) Thresholds and limits; 3) Compound events; 4) Impact (un)avoidability; and 5) Impact (ir)reversibility. Each category intends to help assess whether the adaptation plan or strategy considers key overshoot implications.

The questionnaire had seven questions in total and stakeholders were asked to answer each question using a score between 0 and 4. Lower scores should be assigned when the indicator is not assessed (0); there is some awareness but no explicit assessment (1); or there is partial assessment of the indicator (2). Higher scores should be assigned when there is a comprehensive assessment of the indicator but no implementation in the adaptation strategy (3); or when the comprehensive assessment is reflected in planned actions and implementation (4).

The OPM can help improve already in-place adaptation policies or support in designing new adaptation strategies. However, both situations require knowledge about the hazards and impacts of overshooting global temperatures at the regional and local levels. Therefore, the application of the OPM in the iconic cities requires differentiating and IC-specific approaches, due to the advancements in adaptation policies in each IR/IC. Moreover, this is dependent on input data and models of future scenarios, which is described in the following section.

1.5. Modelling framework applied

The PROVIDE project followed a multi-model framework to provide high-resolution modelling of climate hazards, impacts and risks for each of the ICs. Present day and future scenarios of hazards were calculated using several models:

- Flood4cast (for flooding in Bodø).
- UrbClim (for temperature-related variables in Lisbon and Islamabad).
- UBCWM (for river flow changes in Islamabad).
- CLIMADA (for probabilistic risk assessment and adaptation option appraisal in Lisbon, Islamabad and Nassau).

Each of these models is further described in the following sections.

1.5.1. Flood4cast

Flood4cast is a novel urban flood model that applies a grid-based approach at a modelling scale coarser than most recent detailed physically based models (Craninx et al. 2021). Automatic model set-up based on commonly available GIS data facilitates quick model building in contrast with detailed physically based models. The model integrates hydrological modelling with 2D overland flow and urban drainage flow, while keeping the model equations simple to reduce the computational demand.

In PROVIDE, Flood4cast mainly provides data on pluvial flooding in the city of Bodø (Norway).

1.5.2. UrbClim

UrbClim is an urban canopy model designed to simulate high - up to 30 meters - spatial resolution climate variables at the scale of a city (De Ridder et al. 2015). The model is composed of a land surface scheme with simplified urban surface physics coupled to a 3D atmospheric boundary layer scheme. ERA-5 reanalysis data for the period 2001-2020 is used at its boundary conditions and the surface is defined based on high resolution satellite information, Open Street Map and detailed land use / land cover maps provided by the city (e.g., a tree database, building height information).

The high-resolution land use information on buildings, trees, roads, etc., can be used by the HiREx model (Souverijns et al. 2023; based on Lauwaet et al. 2020 and Liljegren et al. 2008) to calculate meter-scale heat stress information for (parts of) the cities. Heat stress will be depicted as a function of the Wet Bulb Globe Temperature (WBGT). WBGT is an excellent measure of human heat stress as it considers humidity (wet bulb temperature, Tw), radiation (globe temperature, Tg)) & dry bulb temperature (2 m temperature, T2m)).

Future climate change is considered by applying output from MESMER-M simulations for the different overshoot scenarios via a quantile mapping approach onto present-day UrbClim results, as described in Souverijns et al. 2022). This method perturbs the present-day time series to follow future climate conditions from MESMER-M.

Within the PROVIDE project, a set of future scenarios have been defined, corresponding to different emission pathways. These originate from the IPCC Sixth Assessment Report (AR6) scenarios[1], but are somewhat different and correspond to additional future pathways, including overshoot scenarios. With respect to high resolution UrbClim results, we will provide results for the three main scenarios outlined within the PROVIDE project:

- *Current Policies* - This scenario explores the consequences of continuing along the path of implemented climate policies in 2020 with only mild strengthening up to 2100. It illustrates the outcomes of many scenarios in the literature that project the outcomes of current policies.
- *Delayed Action* - This scenario explores the consequences if decarbonisation is delayed in earnest to the 2030s, when energy demand is reduced and the transition to variable renewable energy accelerates. Renewable energy never displaces all fossil fuel use – carbon dioxide is captured from the air and buried instead, along with reforestation. This scenario is referred to as 'Gradual Strengthening' in AR6.
- *1.5°C – Shifting Pathways* - This scenario explores how a broader shift towards sustainable development can be combined with climate policies consistent with keeping warming to 1.5˚C. Energy demand is reduced over time, while renewable energy use grows, squeezing out fossil fuel use. This scenario is referred to as IMP-SP in AR6.

In PROVIDE, UrbClim is applied to the iconic cities of Lisbon (Portugal) and Islamabad (Pakistan), and its application is summarized in Figure 3 below.

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[1] Source: https://www.ipcc.ch/assessment-report/ar6/

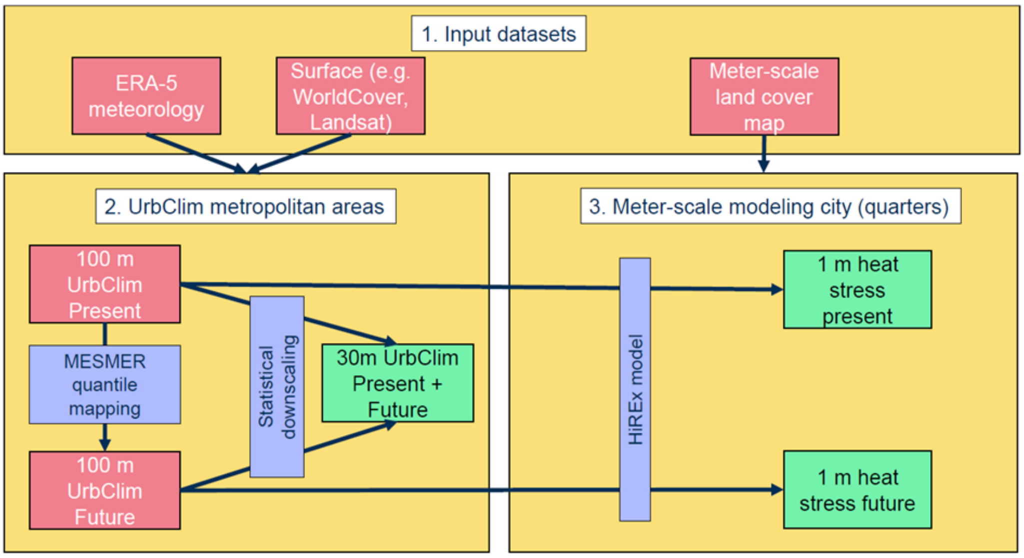

Figure 3: Overview of the applied UrbClim methodology

1.5.3. UBCWM

University of British Columbia's Watershed Model (UBCWM) is a semi-distributed hydrological/watershed model which divides the studied region into multiple elevation bands. This model was developed primarily for mountainous river basins. Using maximum and minimum temperatures and precipitation data, the model predicts/projects streamflow and various other components such as snowmelt and glacial melt, along with their contribution towards the overall streamflow (Figure 4). In addition, the model also provides information on the accumulation and depletion of snowpack, soil moisture budget, soil and groundwater storage, and surface/subsurface components of the runoff (UlHasson et al. 2019).

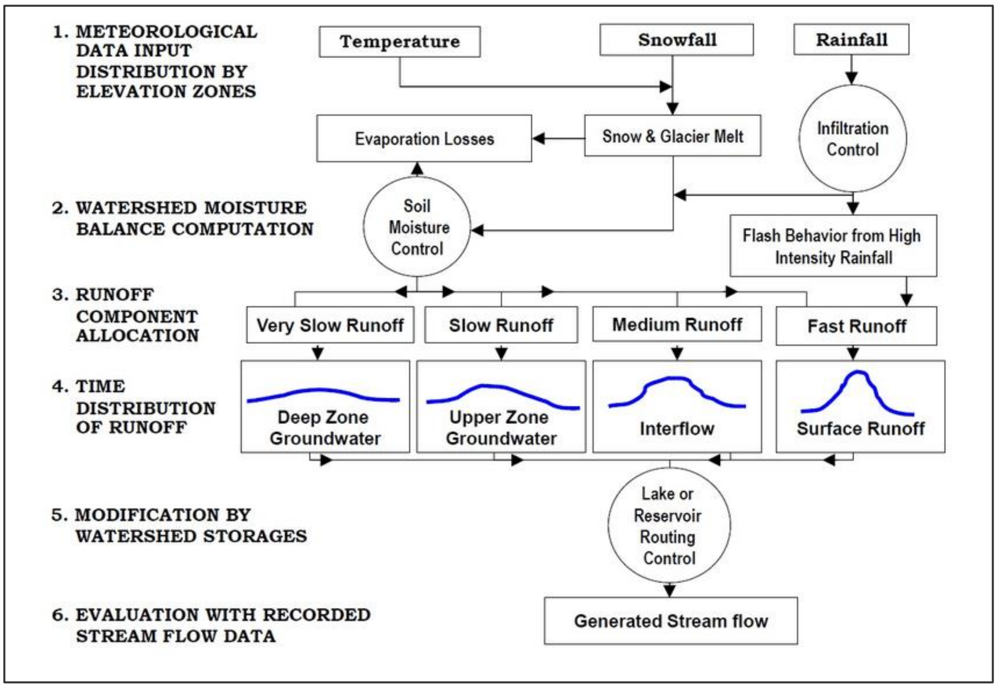

Figure 4: A schematic diagram of UBC watershed model

In various regions including Upper Indus Basin, UBCWM has been widely applied for water resources management, land-use planning, and environmental assessments. It has also been used by Pakistan's Water and Power Development Authority (WAPDA) since the 1990s, for seasonal prediction of river flows in the Upper Indus Basin.

In PROVIDE, UBCWM mainly provides information on the overall water availability in the Upper Indus Basin (including mean and extremes) in response to snow and glacier melting under current and projected overshoot scenarios.

1.5.4. CLIMADA

CLIMADA is a quantitative modelling platform and an open-source globally consistent probabilistic risk assessment and adaptation option appraisal tool written in Python (Aznar-Siguan & Bresch, 2019). It can be used to assess the impact of natural climate hazard events such as heatwaves, floods or tropical cyclones, compute their risk in the climate today or along climate projection pathways, and estimate the cost and benefits of adaptation options. The hazards are modelled as probabilistic event sets described as spatially explicit intensity maps, such as can be obtained from UrbClim or Flood4cast. The exposures are modelled as maps of value that are location-dependent, such as the population density, the physical asset worth, or the ecosystem type. The effect of the hazard on the exposure is characterized by an impact function, which subsumes all facets of the vulnerability. The model is developed and maintained as a community project, and the Python 3 source code is openly and freely available under the terms of the GNU General Public License Version 3.

In PROVIDE, CLIMADA mainly provides data on heat-health-impact in Islamabad and Lisbon, and tropical cyclones in the Bahamas and Nassau.

1.6. Links between the modelling and engagement activities

The co-development of adaptation planning in each IR/IC under different potential overshoot scenarios is based on high-resolution urban modelling provided by several modelling practices, as described above. By combining the modelling tasks with local and regional assessment of risks and responses through the tasks of direct stakeholder engagements in the ICs, we provide a comprehensive adaptation planning opportunity. Moreover, the information gathered and presented both in advanced climate scenario models and Climate Risk Dashboard, together with the self-assessment methodology to be applied and evaluated by adaptation practitioners, bridges the need to couple scientific knowledge with local needs and understandings.

While the high-level data modelling and scientific tools serves the purpose of informing and giving realistic outlooks of future scenarios to plan for, the stakeholder engagement grounds this knowledge both with local adaptation planners needs and, perhaps more importantly, their understanding of how planning for the future cannot go on business-as-usual. In the self-reflection and evaluation of their own policies and plans, the realisation of what specifically is at stake becomes more acute. Hopefully, this will improve local adaptation planning, strengthen local resilience, reduce vulnerabilities, and avoid maladaptation if overshoot scenarios occur.

I. Insights from four Iconic Regions and Iconic Cities

2. Arctic Fennoscandia and Bodø municipality, Norway

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Contributing authors: Arild Gjertsen, Nordland Research Institute; Niels Souverijns, VITO; and Miechel De Paep, BUUR Part of Sweco

2.1. Context and reference

The circumpolar Arctic is warming three times as fast as the global average. While the rate of warming varies, Arctic Fennoscandia – defined as the northernmost countries of Norway, Sweden, and Finland – is facing very rapid warming with shorter and more unpredictable winters. By 2040, most of the region is likely to experience temperature increases of 1.5-2.5°C, and at the end of the century, it may no longer feature a subarctic climate (Bednar-Friedl et al. 2022). Precipitation will increase and more is expected to fall as rain in seasons when snowfall has been the normal. Key climate hazards in this IC include increased precipitation and runoff, and warmer and driers summers, increasing the frequency of forest fires. Local and regional impacts of climate change have the potential to affect national economic interests (forestry and fisheries) as well as non-economic losses related to culture and wellbeing.

Compared to the southern parts of the three countries of the region, Arctic Fennoscandia is sparsely populated but nevertheless feature several medium-sized cities. The analysis of urban spatial structure has focused on Bodø (Photo 1), the regional capital and administrative centre of Nordland County, Norway. With 53 522 inhabitants (Statistics Norway 2023), Bodø is a small and compact city surrounded by coast, high mountains, and forests. It has a multifunctional built-up centre, and peripheral residential areas with a suburban structure.

Photo 1: Bodø, Norway © Helena Gonzales Lindberg

Overall, there is a high adaptative capacity in Arctic Fennoscandia and adaptation efforts are underway. However, there are concerns about lack of awareness, lack of appropriate incentives and directives, and lack of action or too slow action. In Bodø, the main adaptation challenges are related to the expected increase and intensity in precipitation, and threats to infrastructure and lives due to flooding, landslides, avalanches, and storm surges. A storm surge is an increase in water levels, including waves and flooding towards land, which coincide with the usual hide tide fluctuations. This can cause extensive flooding.

Moreover, there is an acknowledged need to increase green areas in the city to better handle surface runoff. Hence, the focus within the stakeholder collaboration of PROVIDE is to look at the risks of flooding and adaptation needs in relations to increasing precipitation. See the full PROVIDE report on overshoot adaptation challenges for Arctic Fennoscandia and Bodø Municipality here.

2.2. Modelling approach to overshoot and adaptation

2.2.1. Data and model setup

A basic flood model for the city Bodø has been set-up to evaluate current and future pluvial floods. In addition, the impact of flood adaptation scenarios on current and future flood events are analysed. In what follows, we explain the data and setup of the model and present the results of from the modelling.

Based on the input data provided, a flood model is set-up for the urban region of Bodø, with a resolution of 1m for the current and future climate. The catchment is first delineated based on the flow paths, calculated on Digital Surface Model data with a resolution of 30m (Figure 5).

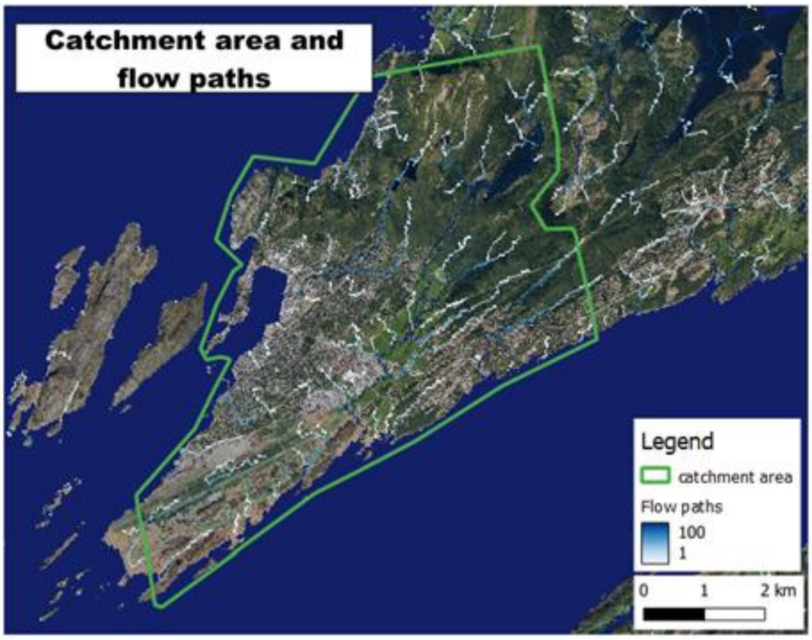

Figure 5: Delineation hydrological catchment Bodø

Based on the location of the sewers and rivers, a surface and urban model layer is built, see Figure 6. The main input is the digital terrain model with a resolution of 1m. For the urban model (right map), only one urban layer is considered because a major part of the city has stormwater sewers. For this reason, a conceptualized storm water sewer network is set-up where the sewers are connected to the sea or rivers in the model area. For the surface layer four rivers are included in the model (left map). Based on aerial photos, the rivers in the input data are examined. In the city the rivers flow into conduits. It is assumed that the water, flowing in the stormwater sewers, can drain, without limitations, to the sea or rivers.

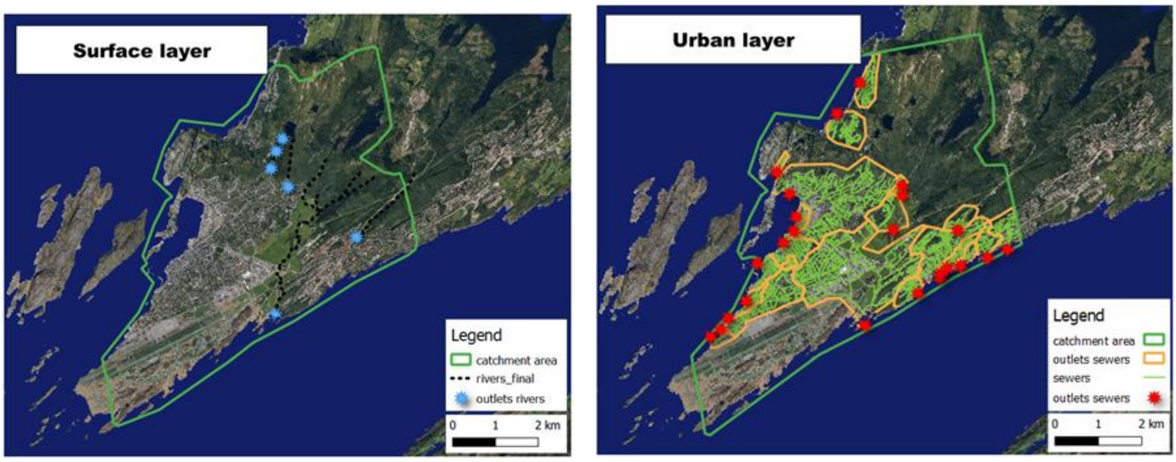

Figure 6: Surface layer (left) and urban layer (right)

Based on communication with the city, the city does not experience major regular floods. All the lakes have flood reduction constructions. Generally, the more modern parts of the city have separated sewer systems and sufficient capacity. Older parts, like Rønvika (located in the northeastern part of the city) does not have separated sewer systems. In this part, the sewer system has enough capacity to avoid flooding in most situations.

On the Norwegian Water Resources and Energy Directorate's *(NVE)* GIS-portal potential flood prone areas are shown, see Figure 7. The NVE's flood caution map is a national map that shows which areas may be exposed to flood risk. The map will never be completely accurate but is good enough to give an indication of where the flood risk should be assessed more closely, if new development is relevant. The information in the map can be used as an initial basis for assessment in impact assessments and/or risk and vulnerability analysis linked to the municipal plan and to identify potential danger areas for flooding. The potential danger areas can be used as a basis for determining flood consideration zones and planning provisions.

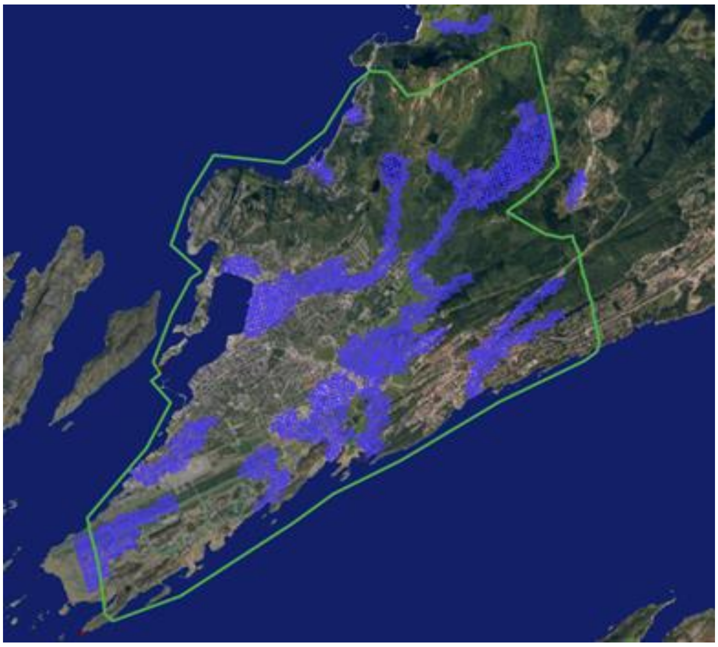

Figure 7: Flood prone areas in Bodø (NVE's flood caution map). Source: https://www.nve.no/map-services/

Bodø municipality has made a quite accurate flood line analysis which can be consulted on the web client of the municipality. Critical locations are also shown in Figure 8.

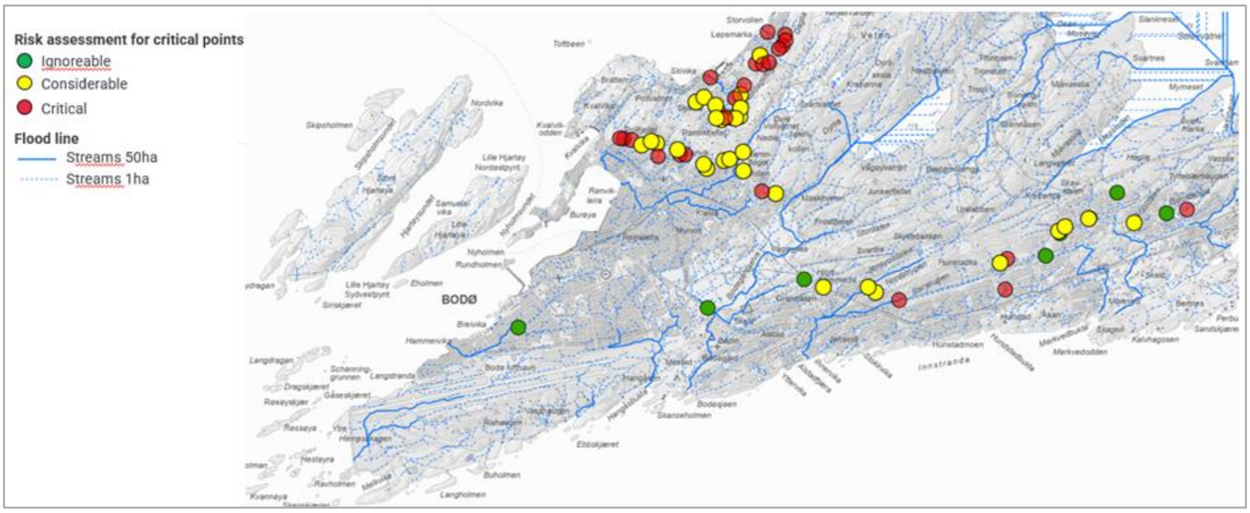

Figure 8: Flood lines and critical points in Bodø[2]

The composite rainfall hydrogram for a storm with a return period of 100 years is determined by extrapolation based on local rainfall data for an observation period of 20 years. Observations are achieved from the Norwegian Meteorological Institute[3]. The peak rainfall during a 5 min period is 59.59 mm/h.

2.2.2. Results from the modelling

The modelled floods with Flood4Cast for a storm with a return period of 100 years are shown in *Figure 9* on the next page, combined with the flood prone areas from the Norwegian website. It can be noticed that the modelled pluvial floods Bodø are rather limited which is in correspondence with the communication with the city. The modelled floods are more limited compared with the flood prone areas. The flood prone areas from the NVE's flood caution map indicates which areas may be exposed to flood risk and are therefore indicative.

At the time of writing this report, the PROVIDE overshoot scenarios were not yet available. Nevertheless, based on CMIP6 data, an indicative simulation was executed for the future climate (2050), see Figure 10 on the next page. The flooded areas in Bodø will increase slightly. The peak rainfall will increase from 60mm/h to 81mm/h which is a rather small increase. The impact of climate change on the flooded areas in Bodø is therefore limited in this case.

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[2] Source: https://bodo-kommune.maps.arcgis.com/apps/instant/sidebar/index.html?appid=287f059a679a424187c91d173e9f8f97

[3] Source: https://projects.met.no/verifikasjon/nedbor.php?st=Bodo&dg=1

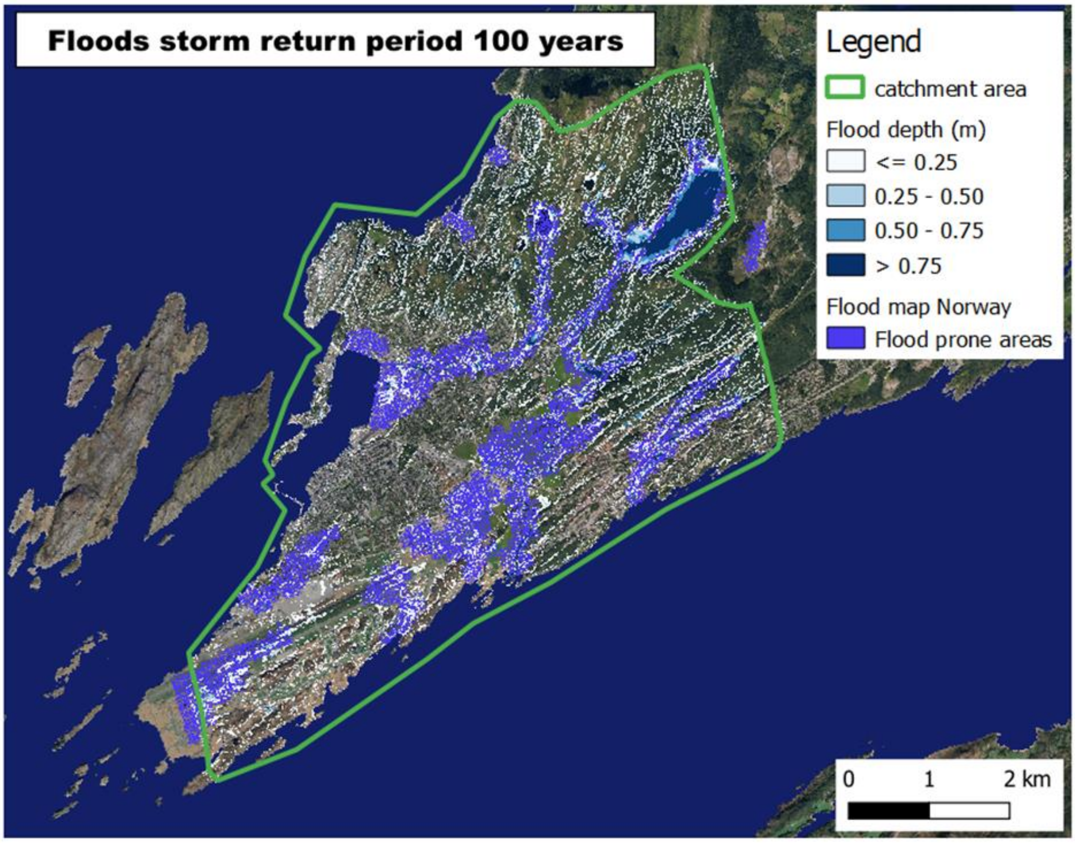

Figure 9: Flood map current climate storm with return period of 100 years (flood depth < 5cm are not shown) compared with the flood prone areas Norway.

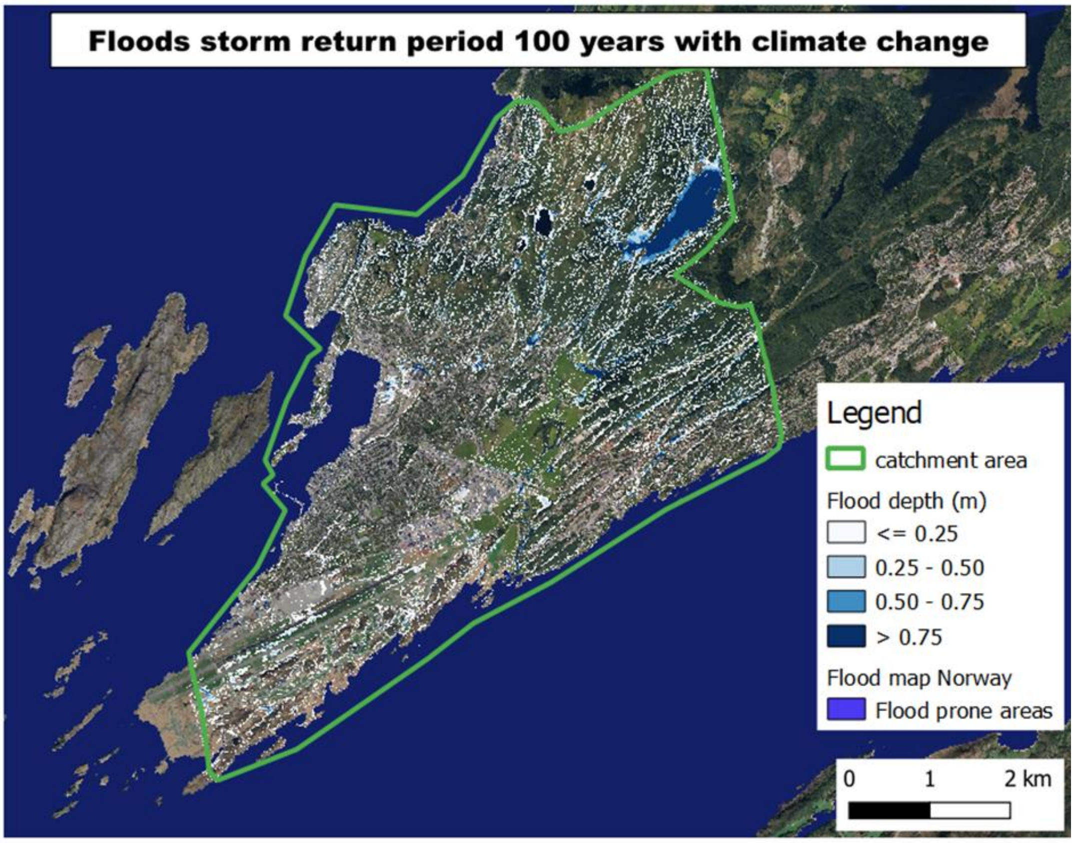

Figure 10: Flood map future climate (2050) storm with return period of 100 years (flood depth < 5cm are not shown)

2.3. Spatial challenges and opportunities for overshoot adaptation

Flood4Cast's analysis, coupled with the available national and local datasets, shows that the flood risk in Bodø is relatively limited. This is also true in a 2050 scenario encompassing the impact of climate change. Therefore, it should be possible to address the challenges for a sustainable water management in Bodø using classic adaptation measures. These include more technical interventions, like increasing the stormwater drainage infrastructure's capacity, and nature-based solutions such as enhancing the soil's natural infiltration capacity through de-sealing of impermeable surfaces. The municipality takes the challenges seriously and has been working over the past several years on an update of the sewerage network. These efforts have entailed network optimization, including separation of wastewater and rainwater conduits, as well as augmenting the overall capacity.

From the perspective of nature-based solutions, Bodø mainly needs more permeable open space to allow for natural infiltration. The spatial strategic profile that was presented in the report on overshoot adaptation challenges, shows that there is still a lot of room for improvement in terms of de-sealing and better interconnection of the green spaces in the city. On the one hand, this concerns the de-sealing of the public space and the many non-permeable private areas (primarily parking lots). The existing green space in Bodo is mainly of a private or semi-private nature. This also poses an important challenge to prevent the further sealing of private gardens for, among other things, terraces, and parking spaces.

If we look closer at the Flood4Cast analysis, we can see that Bodø's city centre is at little risk for flooding, despite the high building density and lack of green space. Potential flood zones are located directly north of the centre (at the level of the industrial zone and further towards *Kleiva)* and in the eastern part of the city. In these areas most critical points are identified by the municipality itself. Especially that northern zone has a lot of impermeable surfaces today, so there is an important opportunity to work on more natural infiltration possibilities through de-sealing of these surfaces. In addition, we believe that a comprehensive strategy for the partial de-sealing of traffic infrastructure (streets, intersections, parking lots) can be an important added value for Bodø. In addition to more infiltration capacity, this also provides many other advantages, in terms of cooling, biodiversity and image quality. In the continuation of the research and the building of the overshoot adaptation narratives, we will further enhance such a comprehensive strategy. Figure 11 gives a spatial framework for this strategy, including potential green corridors that will help to create a robust and resilient green network in Bodø which will improve the infiltration capacity of the urban surface but also the ecological quality of the city. The main focus will lie on the red areas in Figure 11 below, which are now characterized by an increased grade of impermeable surfaces and are in special need for de-sealing. On top of that a more general approach towards the greening and de-sealing of streets will be proposed, combined with micro-interventions for local water buffering and infiltration solutions.

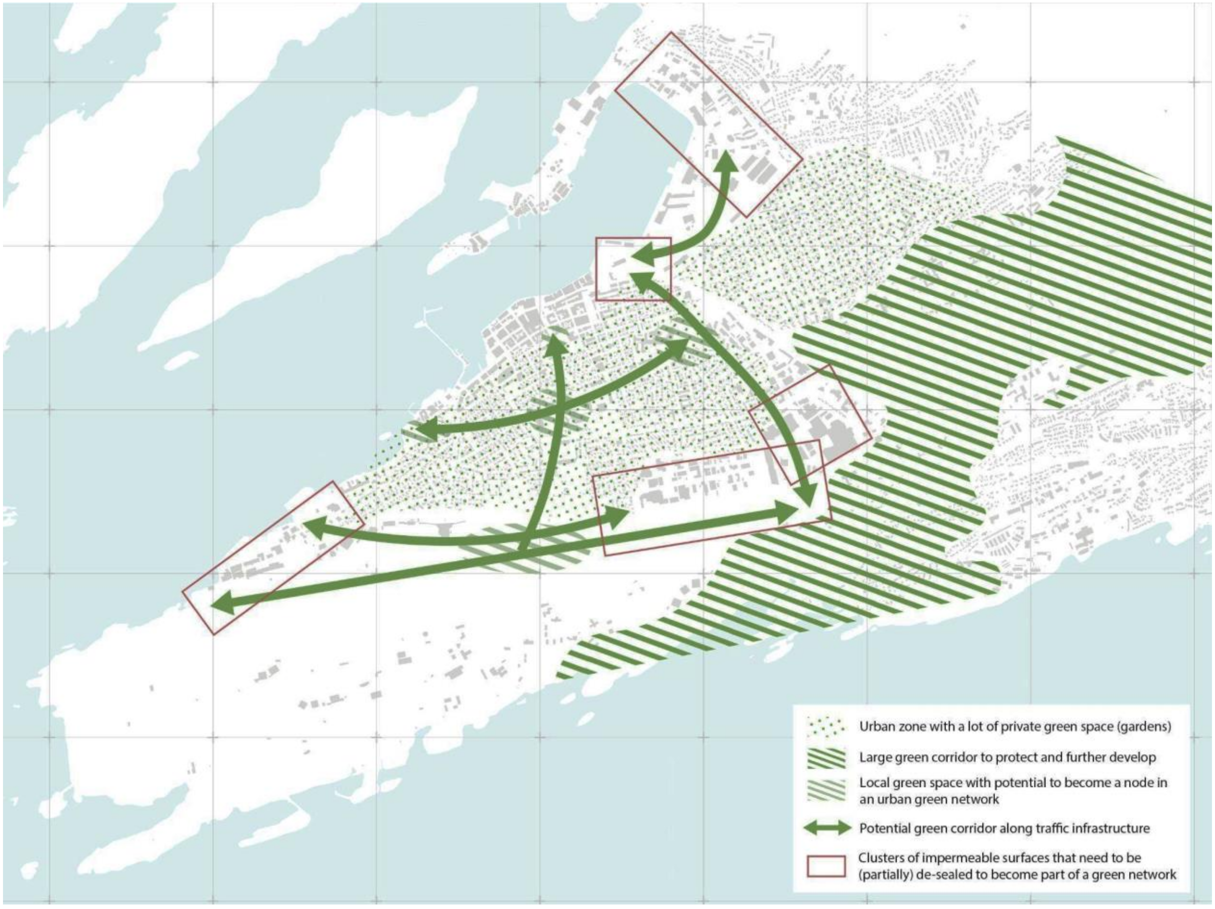

Figure 11: Potential green network for Bodø, with existing and potential green corridors and focus zones for a strategy of de-sealing of zones with a concentration of impermeable surfaces

2.4. Overshoot Proofing and stakeholder co-development Process

The Overshoot Proofing Methodology (OPM) was developed through consultations with adaptation planners through an online survey and workshops with stakeholders in Nordland County and Bodø Municipality as well as drawing on existing literature. The consultations revealed that most respondents had low confidence in the sufficiency of their adaptation plans. Hence, the OPM overall aims are to improve overall adaptation planning, strengthen resilience, reduce vulnerabilities, and avoid maladaptation if overshoot occurs. Additionally, one aim is to formulate and review adaptation policies and plans to integrate the concept of 'overshoot' and its implications for the policies and plans. This is done by working together with stakeholders in Bodø Municipality using the OPM's self-assessment tool. This entails using a scorecard where the policymakers evaluate their own adaptation work.

A workshop was held on the 22 August 2023 in Bodø at the Town Hall (Photo 2). The purpose was to introduce the overshoot proofing methodology and for the municipality employees to self-evaluate its usage and usefulness when considering the adaptation planning in Bodø Municipality. Prior to the workshop, three adaptation plans had been identified for self-evaluation in conversation with the stakeholders: The part about area planning in the municipality plan *(Kommuneplanens arealdel)*; The Climate- and Energy plan *(Klima- og energiplan);* and the risks and vulnerability analysis *(Risiko- og sårbarhetsanalysen (ROS)).* In addition, the score card and guidance for self-evaluation had been translated from English into Norwegian.

Photo 2: Workshop with stakeholders in Bodø Municipality at the Town Hall in Bodø. © Helena Gonzales Lindberg

The workshop started off with a short presentation of the PROVIDE-project, including an explanation of the concept "overshoot" and limits to adaptation. Here we explained what the project is about and emphasized the importance of stakeholder interaction in the work with developing tools for adaptation planning under overshoot scenarios – such as the overshoot proofing methodology and the PROVIDE Climate Risk Dashboard. Then we went through the methodology of self-evaluation. However, instead of focusing on one plan at the time, the participants found it most useful to evaluate the overall, current adaptation work and plans for Bodø Municipality in the light of the three already mentioned adaptation plans. A question was raised whether this was going to be an actual evaluation, hence, the organizers emphasized that the focus was to evaluate the usefulness and value of the overshoot proofing methodology for the participants' work with adaptation planning. Therefore, each question in the scorecard was discussed without emphasizing the "score point" as such. The most interesting was how the participants understood the evaluation questions and process. Further reflections on the OPM from all IC/IR are discussed in Chapter 6.

In the following we present the seven questions from the OPM score card and the discussions and questions raised in relation to each question during the workshop:

Question 1: Global warming scenarios

When discussing about whether different scenarios for global warming had been assessed in the adaptation plans, several points were raised. It was raised whether the question related to scenarios generally or specifically three scenarios where the mean global temperature has increased with 1,5°C, 2°C and 3°C. Do the plans have to relate to these scenarios in particular? It was highlighted that planners look at the increases in magnitude and frequency of events rather than specific scenarios related to certain warming degrees. Moreover, in regard to sea level rise, the consideration was rather on frequencies of 100-years and 200-years flooding.

There was also a suggestion that there needs to be another alternative on the list of points between 2 and 3 – An alternative that "One scenario is assessed and is used to plan adaptation". It was mentioned that most municipalities in Norway have made adaptation plans and measures, although not necessarily considered one specific future global warming scenario and/or only used one scenario.

"Climate surcharge" *("Klimapåslag")* was mentioned as the way that unknown futures are dealt with in adaptation planning. It was discussed whether it was good to always plan for the "worst-case scenario" through such surcharge; that this was neither always possible nor useful as there are risks for maladaptation – to "plan too much" according to events that will not happen. In relation to this it was raised that the economic aspects of adaptation planning were lacking in the scorecard's considerations.

The planners also recognized a difference between considering scenarios contra implementing adaptation measures, and perhaps this should lead to two different lists of criteria definitions. Furthermore, questions were raised about how to evaluate different global warming scenarios specifically for Bodø municipality: Where can we get the necessary knowledge to evaluate this? This local knowledge is central if the planners are to convince politicians about the seriousness of different scenarios of global warming.

Questions 2 & 3: Thresholds and limits to adaptation

The questions about thresholds and limits kicked off good conversations and discussions among the participants. A question was raised on what the specific changes (caused by climate change) pointed to in question 2. This question would perhaps be easier to answer if considering one plan/measure independently as it would make it more concrete.

When discussing question 3 about whether thresholds and/or limits had been identified, it was mentioned that the planners work with precautionary models and there are difficulties with assessing probabilities. Here they consider more the reoccurring intervals of specific events, as well as some thresholds and soft limits where it is recognized that to, for example, secure flood ways one must allow water to flow on the ground surface at a certain point as part of the adaptive measure. It was also discussed that differences between mitigation, which is more pronounced at the political level, while adaptation is less politically "popular" and more something that the administration works with.

Question 4: Compound events

The question about climatic and non-climatic risks that can happen simultaneously, opened a conversation about different scenarios and possible events that potentially can occur at the same time in Bodø. Many examples of risks were mentioned but not all climate change related. Many different risks are mentioned in the risk assessment plan but not necessarily considered together as probably compound events. The preparedness work in the municipality does consider extreme weather events, for example, if all communications are closed down due to a storm. However, there was less concern about the sources of a climatic event (whether due to climate change or not), as this did not affect the response needed.

The risk assessment *("ROS-analyse")* will be revised in the near future. Today, different risks and scenarios are considered but not necessarily related to the probabilities of compound events in the face of climate change. In the case of Bodø, it becomes central to consider events where certain more peripheral parts of the municipality becomes totally isolated due to climatic events. Here it was raised that it is not only climate change in Bodø and Northern Norway that needs to be considered when thinking about compound events. Additionally, climatic risks and events outside Norway and even Europe may affect the populations in Northern Norway, exemplified with the consequences of bad harvests in other parts of the world that Norway depends on for food imports. The war in Ukraine, although not related to climate change, was also mentioned as an example of events elsewhere that affect the preparedness in Bodø municipality.

Question 5: Impact un/avoidability

When discussing avoidable and unavoidable impacts, the response was that most consequences have been dealt with as unavoidable and that it might be more fruitful and effective to highlight the avoidable impacts. This would make it possible to show what the municipality can do locally to deal with the impacts related to climate change. Regarding the score "point" zero, it was lifted that there is a difference whether concepts are new to the adaptation planners (as in "never heard of or worked with before") or whether the concepts have been newly introduced into the adaptation planning.

Questions 6 & 7: Impact ir/reversibility

Overall, in the work with the score card it has become obvious for the researchers that the translation of the indicators, questions and "score points" is a difficult and time-consuming task and that the English version must be tailored in a way so that translation becomes more straight forward. Not only are the concepts used difficult to find translated concepts for, the way that the sentences have been built up also increases the chances of essential parts being lost in translation. Moreover, some of the confusion with what the questions meant or what the score points referred to could have been avoided if the English original was more straight forward. Translation of the terms are essential for good conversations and grounded discussions that relate to the stakeholders' actual working situations.

Comments regarding the PROVIDE Climate Risk Dashboard was related to the data input to the tool: how continuously is it being updated? Can we trust the data to be up to date? It was important for the adaptation planners to know if they could at any time trust the actuality of the information given by the Dashboard.

Photo 3: Participants from the municipality and senior researcher Arild Gjersten from NRI and PROVIDE. © Helena Gonzales Lindberg

Overall, it was a successful workshop insofar the discussion on the topics that the score card raised were fruitful and the participants engaged a lot in conversations and discussions with each other on the issues that overshoot proofing entails (Photo 3). It was clear that overshoot has consequences for adaptation planning in Bodø Municipality although there might be less focus on the topic of overshoot per se.

2.5. Reflections on the co-development process

The stakeholders in Bodø Municipality were essential in the selection of which adaptation strategy to consider for overshoot proofing using the OPM. Also, the entire process of evaluating the usefulness of the Overshoot Methodology, as described above, was framed by the participants from Bodø Municipality, who were eager to discuss these issues more in a holistic way rather than evaluating each question with a score. This indicates that the scorecard and the methodology can be used as starting points for discussing overshoot adaptation planning rather than evaluating measures. The stakeholders in Bodø found it useful and interesting to talk about concepts and problems.

Lack of awareness and lack of funding for adaptive measures have earlier been identified by participants in the PROVIDE-workshop in 2022. This was also raised during the latest workshop. The stakeholders missed a more socio-economic approach to the questions of overshoot planning and how to, for example, convince policymakers to make investments based on future models and scenarios that stretch far into the future compared to the four-year rotation of the electorate. Overall, the practical significance of the OPM for adaptation planning in Bodø remains to be seen. However, there is an increased focus on sustainability issues related to municipal planning in the Norwegian national guidelines and expectations where municipalities and counties are identified as key actors in realizing the UN Sustainable Development Goals (SDGs) in Norway. It has been asserted that the SDGs should form the basis for societal and spatial planning. The current national expectations for 2023-2027 specifies these areas where Norway faces particular challenges: reducing greenhouse gas emissions, responsible consumption and resource use, conservation of biodiversity, and reducing inequality. Climate adaptation is less visible, however, but it is part of the national expectations requiring political action and prioritization. The tools provided by the PROVIDE project, the OPM and the Climate Rish Dashboard, offer timely support both for awareness raising and the political processes for how to prioritize local adaptation goals in Norwegian municipalities and counties.

3. Iberian Mediterranean and Lisbon Metropolitan Area, Portugal

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Contributing authors: Inês Gomes Marques, FC.ID/University of Lisbon; Niels Souverijns, VITO; Chahan Kropf, ETH; Sarantis Georgiou and Miechel De Paep, BUUR Part of Sweco

3.1. Context and reference

The Iberian Mediterranean is broadly defined as the area covering the southern half of Portugal, and the south, central and eastern areas of Spain, including the Balearic Islands[4]. These are areas that have a distinct hot-summer Mediterranean climate or are transition areas that may include already semi-arid and arid climates and environments. The Region has a total population of about 38 million (as of January 2020[5]). Demographic dynamics show a concentration of the population along coastlines and in metropolitan areas. Increasing desertification and ageing in the interior areas have implied a reduction in agroforestry activity and an increase in the risk of forest fires. Intense seasonal population movements associated with summer tourism further increase vulnerability in areas already very sensitive to droughts.

Photo 4: Lisbon Metropolitan Area, Portugal © Abílio Leitão

The selected Iconic City for the PROVIDE project is the Lisbon Metropolitan Area (Photo 4), composed of 18 municipalities. In this case, and despite each municipality having its own elected authority with specific sector policymaking, the Metropolitan office is a public association of territorial incidence that includes climate action and sustainability in its remit (other areas include, e.g., transports and housing). This factor along with the fact that the areas' president is elected from among all 18 municipalities, provides for an initial degree of a metropolitan adaptation governance. This has recently led to the adoption of

[4] For the purposes of the PROVIDE-project.
[5] Source: https://ec.europa.eu/eurostat/web/main/data/database

a Climate Change Metropolitan Adaptation Plan[6] and the development of multiple projects that aim to reduce the area's vulnerability to climate change[7].

The Iberian Mediterranean and the Lisbon Metropolitan Area (AML) are exposed to a wide range of climatic hazards, making it one of the most vulnerable European mediterranean areas to the impacts of climate change. Extreme temperatures are one of the most tangible climate-driven changes occurring in the region, with wildfires and fire hazard conditions significantly increasing over time and causing major disruptions to human and natural systems. Additionally, the concentration of population in metropolitan areas has largely increased the exposure to the urban heat island effect and heatwaves posing substantial challenges to infrastructures, energy system and human health systems. Water stress and scarcity with more frequent and severe droughts have been described as major sources of change affecting the provision of ecosystems services and agricultural output, including leading to crop production failures. The agricultural sector is very exposed in the region, with irrigation playing a key role in the assurance of agricultural viability. The increase in the frequency and intensity of heatwaves and droughts (sometimes in the form of compound events) is set to promote a reduction of water availability for irrigation, further increasing the sector's vulnerability. The effects of diminishing water availability in the region may furthermore include impacts on other key sectors, such as tourism, energy production and drinking water for human consumption. Because of its extensive coastal areas, the region is particularly exposed to storms (which in the case of the Atlantic coastline may include tropical hurricanes), extreme precipitation events and sea level rise. Combined impacts from rising sea levels, storm surge and heavy precipitation events significantly increase the vulnerability and flood risk of low-lying coasts, estuaries, and coastal cities across the region.

There are a number of adaptative capacity components that contribute to the region and its metropolitan areas' climate adaptation challenges and constraints. Firstly, from a regional's perspective both Portugal and Spain present a distinct governance structure that limits a joint adaptation response to some of its transnational climate change challenges. This is clearly seen in areas such as transboundary water resource management, biodiversity and nature conservation, wildfires, and other development or disaster risk reduction policies including coastal management and tourism. Portuguese regions do not have the same level of authority as Spanish ones, making any joint effort on these matters a discussion between a (national) central government and a set of regional governments. Additionally, Spanish regional administration's climate and other sectoral policies are not necessarily fully aligned with Spain's central government policies in the field. In turn, the Spanish central government also dialogues with the Portuguese government on its own climate risk management priorities and transboundary hazards (e.g., drought, biodiversity, among others). This creates a complex landscape of policies and plans, which are necessarily a challenge to the development of a common approach to climate change adaptation in the Iberian Mediterranean area, hence curtailing a sense of common adaptative capacity and making adaptation governance in the region incipient, with the notable exception of some recent efforts by both countries' Environmental Agencies.

[6] https://www.aml.pt/en/areas-atividade/ambiente-e-acao-climatica/#post-content
[7] https://www.aml.pt/en/iniciativas/clima-aml/

After initial contacts with stakeholders and practitioners in the region and after discussion with the project team, heat related impacts were selected as the most critical to be assessed for the AML and therefore underline all the analysis presented below.

3.2. Modelling approach to overshoot and adaptation

3.2.1. Urban Heat Stress Assessment using UrbClim model: Lisbon Metropolitan Area

To capture, quantify and disseminate information regarding heat stress in cities, a detailed set of heat stress indicators is defined and calculated at 100 m spatial resolution (listed in Annex 8.1). Apart from these standard indicators, city-specific heat stress indicators are offered in consideration with the local stakeholders. Below, the Urban Heat Island intensity during night-time is shown (*Figure 12* on the following page: full definition in Annex 8.1). The cities pop up as being much warmer during the night compared to its rural counterpart, with temperature differences exceeding 3 °C. There is however quite some spatial discrepancy.

Firstly, the Monsanto Parc in Lisbon, denoted by 1 in *Figure 12*, is a nice example of a ‘cool island’ within the city, characterised by large amounts of vegetation and urban trees.

Secondly, more subtle differences within the Metropolitan Area are present, being slightly warmer or cooler compared to other parts. The industrial area in Barreiro-Lavradio, denoted by 2 in *Figure 12*, exhibits Urban Heat Island intensities that are approximately 1°C higher compared to other nearby urbanised areas. This area is characterised by high densities of sealed surfaces and concrete. In combination with the high number of open spaces, solar radiation can efficiently penetrate and be absorbed by these surfaces, leading to extra heat storage, which is released during the night.

Thirdly, the city of Lisbon, denoted by 3 in *Figure 12*, shows a pattern of warmer temperatures in the old city (southern part of the inset) compared to the more outskirt areas (e.g., northern part of the inset). The old city is characterised by higher building densities and the limited available open space is sealed, while the north-eastern part of the city is structured towards more open space between the buildings, in which urban green and trees are present. Their evaporative capacity helps cooling these parts of the city, leading to lower Urban Heat Island intensities.

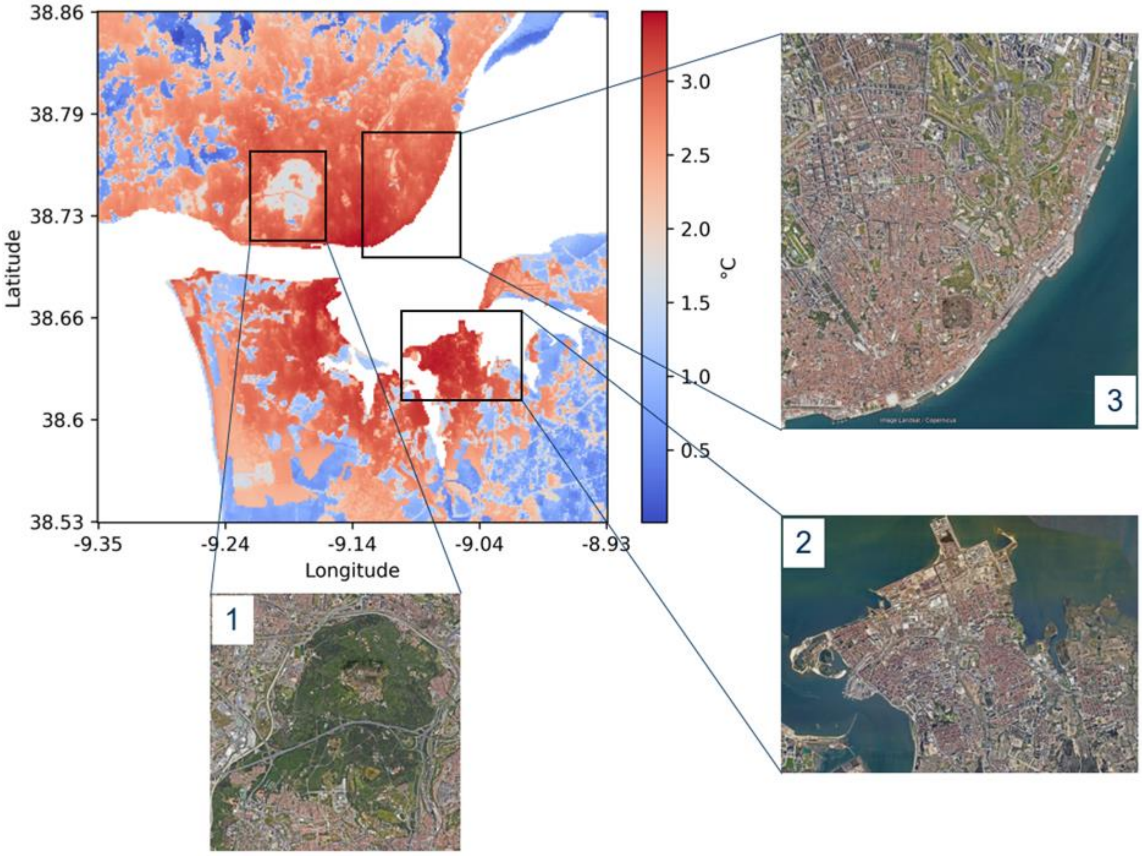

Figure 12: Night-time urban heat island intensity. Three areas are highlighted (1: Monsanto Parc, 2: Barreiro-Lavradio industrial area, 3: Lisbon city centre with an increased vegetation cover towards the north).

At 1 m spatial resolution, heat stress is depicted very detailed, directly accounting for the impact of solar radiation on individual features and considering building and tree shades. Average daily heat stress levels for a clear-sky summer day (16 July 2020) are depicted in Figure 13 on the next page. Similar to the Urban Heat Island, trees provide efficient tools for heat stress alleviation, as here, lowest heat stress levels are found. The extended forest of Monsanto Parc appears most efficient and has a much higher cooling potential compared to the individual trees that are in the city centre. These latter however still lower heat stress levels, certainly when they are grouped and consisting of large tree crowns (denoted by 3 in Figure 13).

Generally, open spaces and sealed surfaces exposed to direct sunlight experience highest heat stress levels (as visible in area 2 in Figure 13). Notable is that in the city of Lisbon these higher heat stress levels are also present in parcs that are characterized by open grass fields, as is visible in the northern part of the city (denoted by 1 in Figure 13). Here, we even register higher heat stress levels in these open spaces compared to the built-up area just north. This can be explained by the configuration of these built-up structures, consisting of high-rise buildings, with limited sealed surface and high amounts of trees in between. These offer a high amount of shade during most of the day, providing nearby cooling and lower heat stress levels for most citizens in the area.

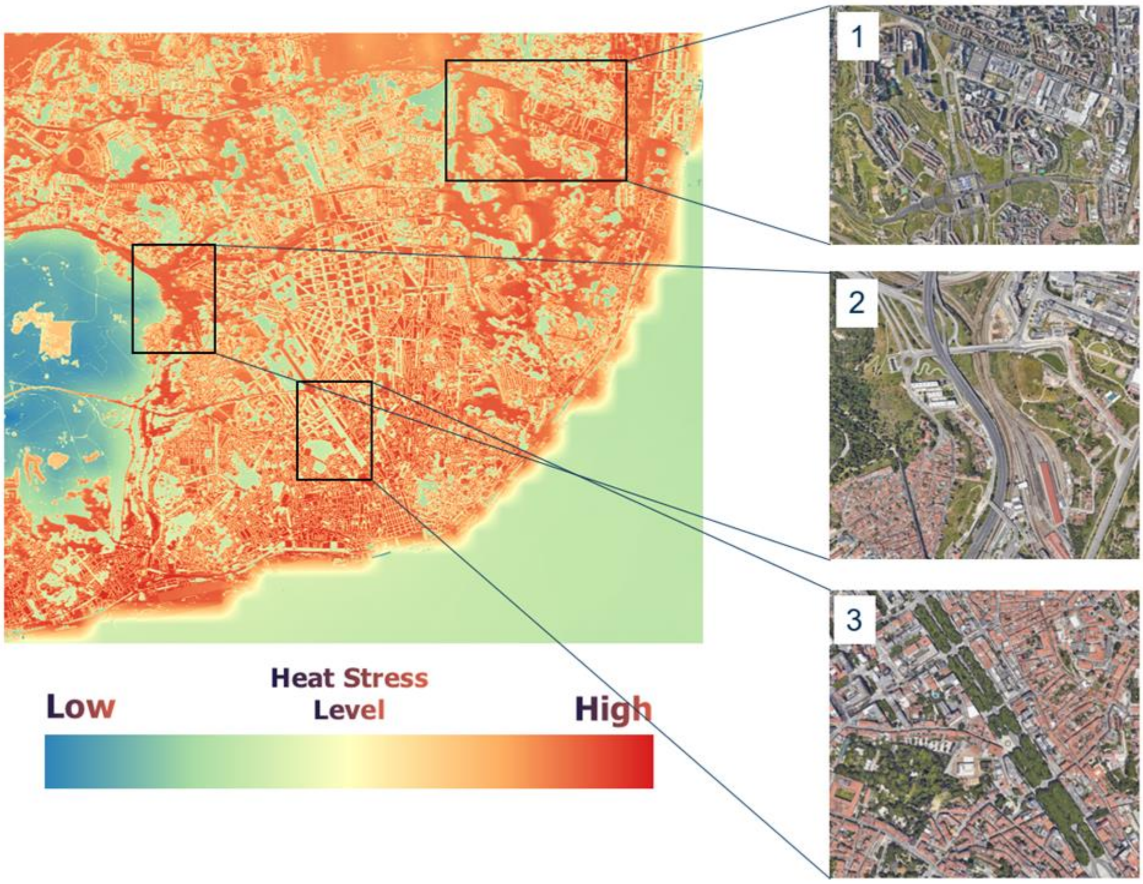

Figure 13: Heat stress levels at 1 m spatial resolution for the city of Lisbon. Three insets with different urban morphology are shown

Apart from present-day, also simulations for future climate have been executed, both for the city and the full metropolitan area. The temperature changes for Portugal with respect to pre-industrial temperatures for the overshoot scenarios "Current Policies", "Delayed Action" and "1.5°C – Shifting Pathways" are shown in Figure 14 below.

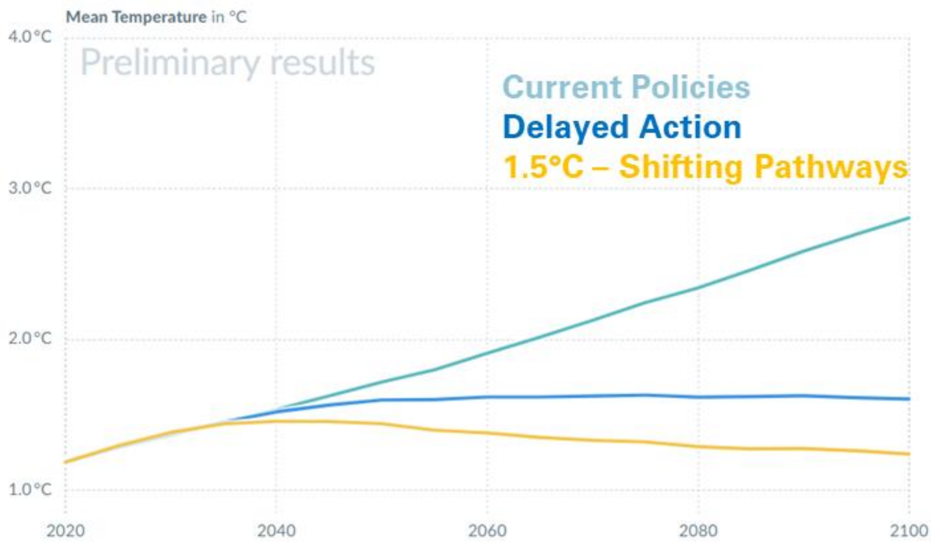

Figure 14: Temperature changes for Portugal with respect to pre-industrial temperatures for the scenarios of "Current Policies", "Delayed Action" and "1.5°C – Shifting Pathways" coloured in light blue, dark blue and yellow, respectively.

For each of the indicators listed in Annex 8.1, we will provide decadal projections up to 2100. These maps, adapted for the PROVIDE scenarios, will provide the input for the PROVIDE dashboard. An example is given below for the full metropolitan area, showcasing the number of heatwave days at present day and for the three scenarios above by mid-century (2050). A full definition can be found in Annex 8.1. A clear increase in heatwave days can be expected, most pronounced in the highest warming emission scenario, but also in case of moderate warming, a significant increase in heatwaves is expected. See Figure 15 on the next page.

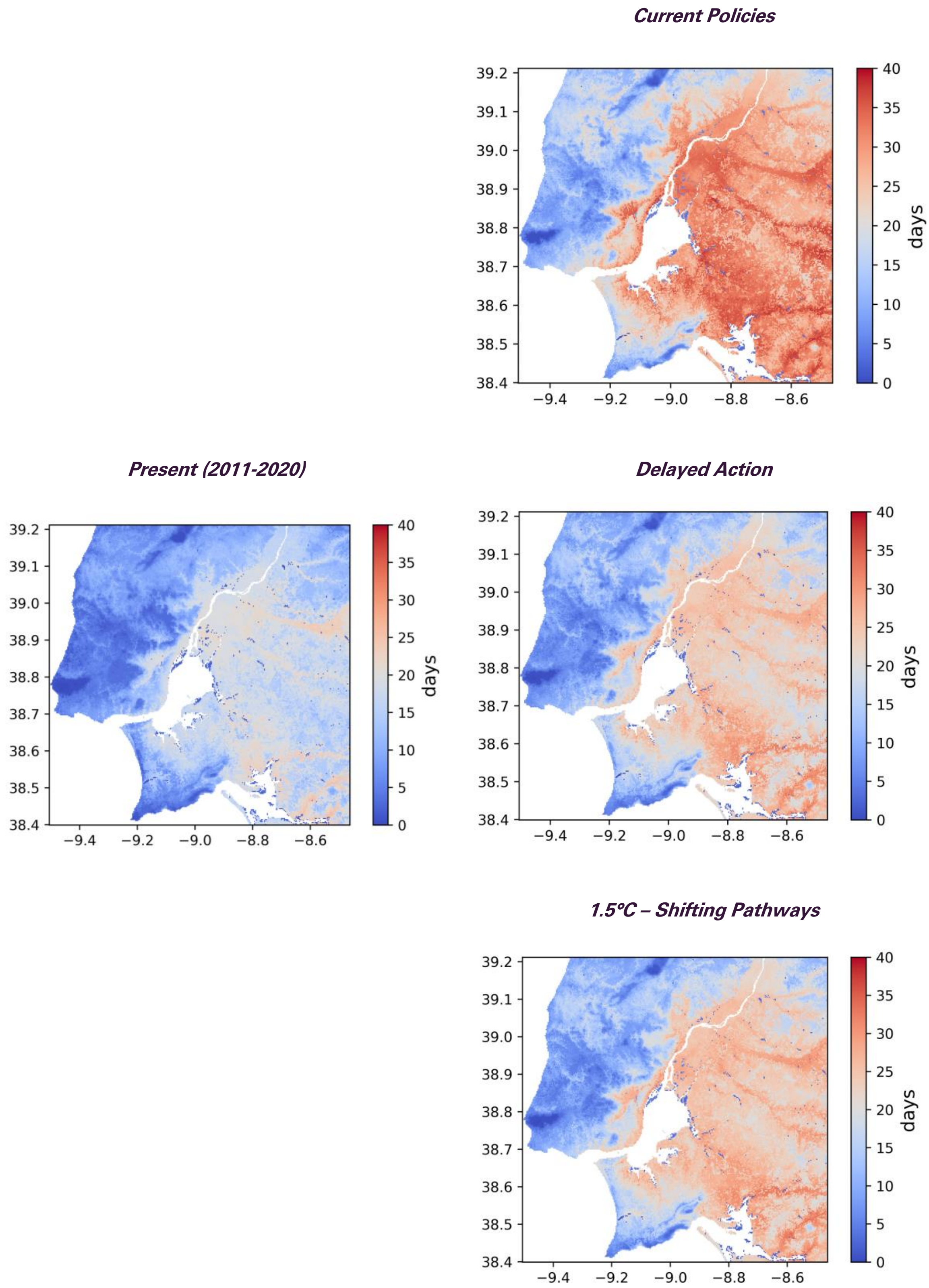

Figure 15: Number of annual heatwave days in present times (2011-2020; left) and by mid-century projected under the different PROVIDE scenarios (high emission) (2041-2050; right)

3.2.2. Urban Heat Impact Assessment using CLIMADA model: Lisbon Metropolitan Area

As described in the previous section, heat stress can be a serious challenge in urban areas. In general, heat stress will be exacerbated in a future warmer climate, which may have serious impact on human health and well-being. To better understand these impacts, and in order to enable the assessment of adaptation strategies, exposed population as well as their vulnerability needs to be considered.

In this assessment, differentiated impacts from a single hazard are considered. More precisely, the impact of heat during days and nights on the health of exposed population is studied. These will in turn, serve as indicators for the assessment of different kinds of adaptation options. While during the day many behavioural adaptations such as changing working times, emitting weather warnings, or accessing shaded areas may be possible, for the night more individual and structural adaptation such as house isolation, air conditioning or ventilation corridors might be required.

For exposed population, the WorldPop dataset at 100m resolution, UN adjusted and constrained from the year 2020, was used. While it would be beneficial to include future projections of population into the model for mitigation discussions, it is not clearly beneficial for adaptation option appraisal as discussed here. Indeed, much of the details in urban development may be sensitive to urban planning, district laws and general trends, which makes any future projections difficult. Instead, general development might be considered as one of various possible adaptation measures. Thus, for all times, the same static population dataset shown in Figure 16 is used. For later analysis, the impacts are aggregated on the parish levels (NUTS3) indicated in Figure 16.

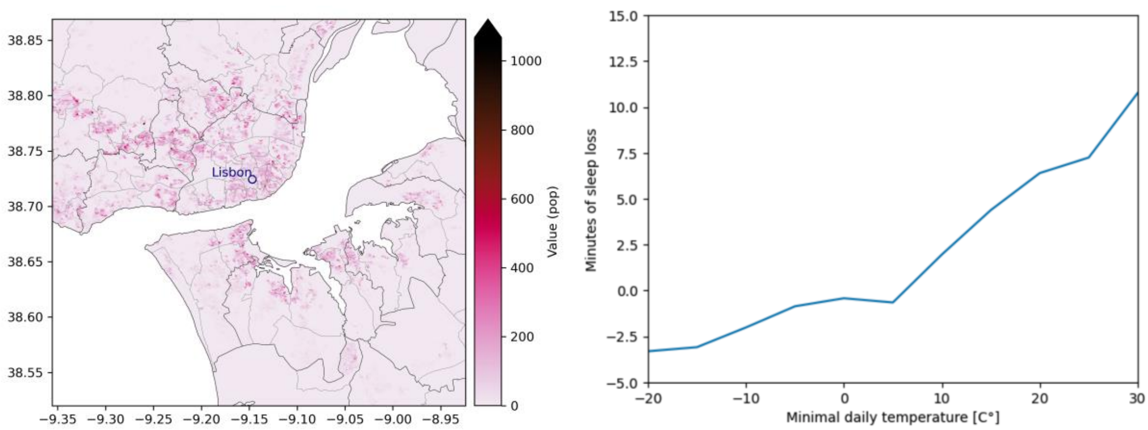

Figure 16: Left: Population exposure distribution for Lisbon at 100m resolution as provided by WorldPop for 2020 and divided in the NUTS3 administrative unit boundaries provided by the Portuguese government https://www.dgterritorio.gov.pt/dados-abertos. Right: impact function for the loss of minutes of sleep in function of the minimum daily temperature. Note that negative values mean an increase in sleep with respect to the norm. Data taken from Minor et al. (2022)

Two heat impacts were modelled explicitly as general proxies for potential adverse effects of increased daily and nightly temperatures. During the night, most people are occupied with sleeping which is known to be important for Human health in general. Increased heat disrupts sleep and leads to a decrease in sleeping time. This effect is modelled by an impact function which relates the daily minimum temperature to the average loss in minutes of sleep based on the findings of Minor et al. (2022) as shown in Figure 16 above. For the day, the number of heatwave days per year is used. For Lisbon, a heatwave is defined as at least 6 consecutive days with maximum daily temperatures 5 °C above the reference period (2011-2020) average maximum daily temperatures.

Daily changes in the number of minutes of sleep loss for the whole region were obtained using the CLIMADA framework (Aznar & Bresch, 2019) by combining the daily minimum temperature time series computed with the UrbClim model for three climate scenarios, the population distribution exposures, and the sleep loss impact. function, Analogously, the yearly heatwave counts were used to obtain the number of people affected per year.

As shown in Figure 17 below, with rising temperatures the overall sleep loss in the city increases, which may have effects on health, children education, worker productivity, and more. Under the “Current Policies” scenario, the average increase in sleep loss is up to 17%, which could have dramatic consequences on general health without adaptation. For the “Delayed Actions” and “1.5℃ – Shifting Pathways” scenarios the loss is at most 5%, which is more than 3 times less than under current policies for which the 5% threshold is crossed in 2030-2040 already. In contrast, for the “1.5℃ – Shifting Pathways” scenario, the maximum is reached in 2040-2050, while for the “Delayed Actions” scenario it is reached in 2070-2080. At the end of the century, the increase stabilizes at 2% and 4% respectively. Similarly, in the “Current Policies” scenario the number of heatwave days per person may increase by up to 100%, which could put vulnerable population at very acute health risk (Lüthi, S et al. 2023). For the “1.5℃ – Shifting Pathways” and “Delayed Actions” scenarios the maximum increase is less than 30%. For the former, the maximum is reached in 2040-2050, while for the latter it is in 2070-2080. At the end of the century, the increase stabilizes at 15% and 23%, respectively.

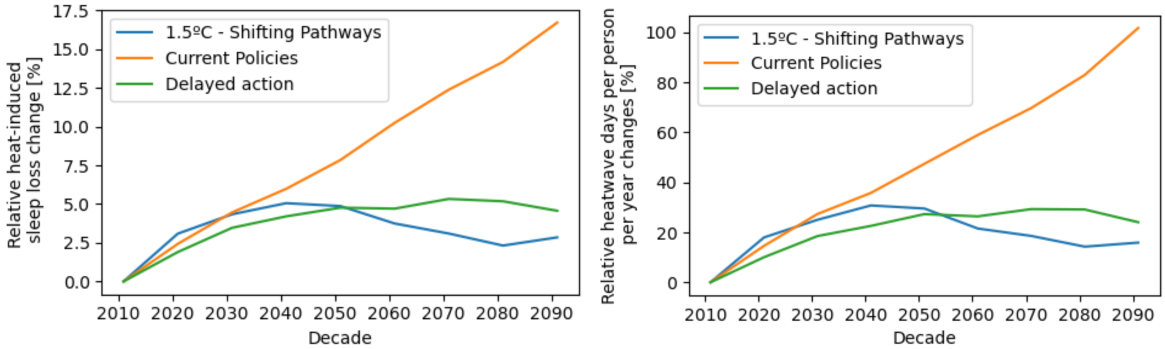

Figure 17: Relative change in the heat-induced sleep loss (left) and heatwave affected people (right) impacts per decade with respect to the reference period 2011-2020 for the three emission scenarios “1.5℃ – Shifting Pathways”, “Current Policies”, and “Delayed Action” as provided by UrbClim (cf. Section 2.2.1). The x-axis represents the beginning of the following decade

The distribution of both impact is inhomogeneous over the metropolitan areas parishes as shown in Figure 18 on the following page. In particular, the increase in heatwave days/person may be up to 1000% under “Current Policies” scenario in certain parishes (e.g., northwestern parishes by the end of the century). While this might lead to catastrophic impacts on health, it also highlights where the potential benefits of urban adaptation, such as creating natural ventilation corridors, improving building insulation or adding air conditioning to residential buildings, could be most needed.

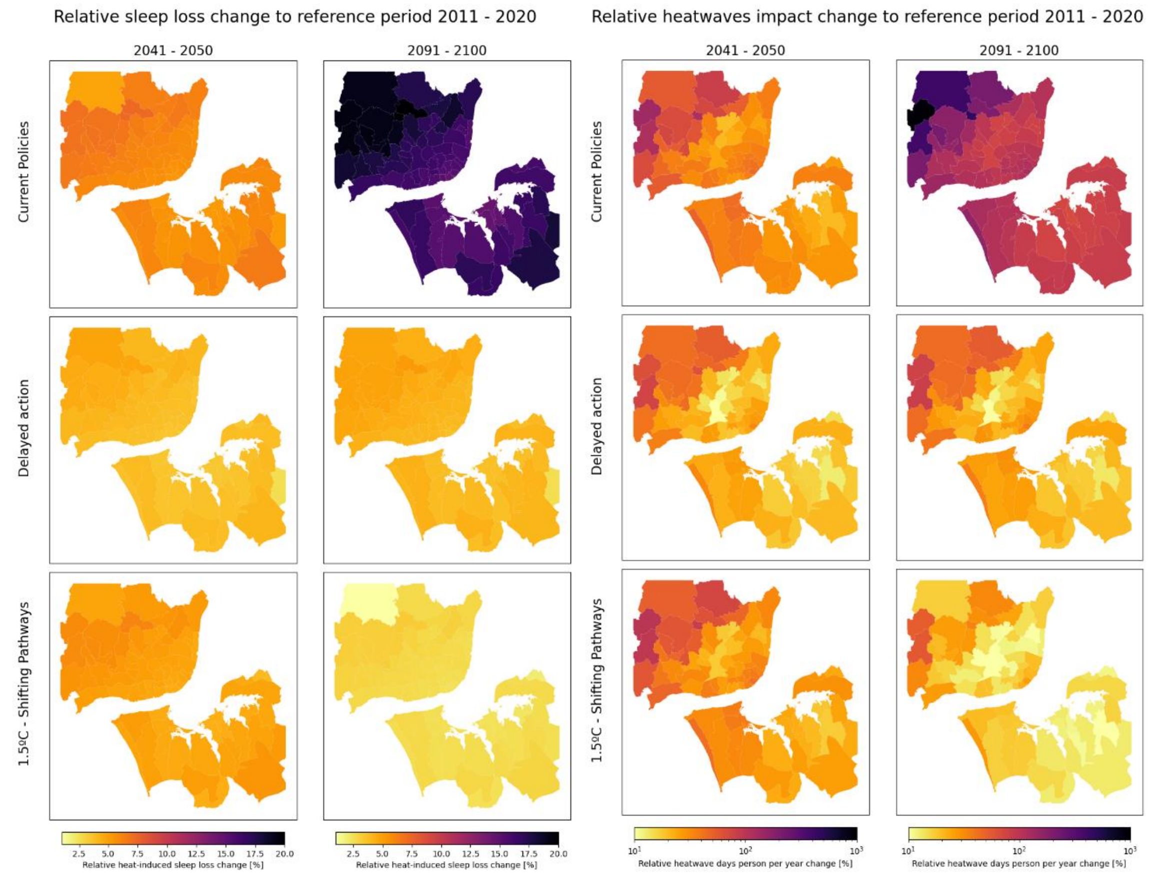

Figure 18: Relative change in heat-induced sleep loss (left) and heatwave affected people (right) per parish for the decades 2041-2050 and 2091-2100 compared to the reference decade 2011-2020 for the three emission scenarios "Current policies", "Delayed action" and "1.5 °C – Shifting Pathways", as provided by UrbClim (cf. Section 2.2.21)

Note that the future projection of the daily urban heat is currently only available for the subset of the PROVIDE overshoot scenarios "Current Policies", "Delayed Action", and "1.5ºC – Shifting Pathways". Note also that the current model includes the city of Lisbon, as the heat data for the whole AML will be available only in the near future. Data and maps for both type of impacts for all decades until 2010, with relative and absolute values, adapted for the PROVIDE scenarios, at different levels of (dis)-aggregation for the whole metropolitan area will be made available as input for the PROVIDE Risk Dashboard.

3.3. Spatial challenges and opportunities to overshoot adaptation

The work that has been carried out under the PROVIDE report on overshoot adaptation challenges sought to map the areas of the spatial structure of the AML and the municipality of Lisbon that are critical for their adaptation to higher temperatures and the mitigation of the effects of heat stress and the Urban Heat Island.

The premise is that to address a particular risk (here: heat stress), space must be organized in a way to provide corresponding services (here: primarily, heat regulation). For space to provide said services, it has to be organized in a way so as corresponding functions are manifested (here: shading, evapotranspiration, heat reflection, cooling, and air filtering). The manifestation of the aforementioned spatial functions is furthered by corresponding strategies and measures (here: soil unsealing, increase in vegetative and surface water land covers, enhancement of the quantity and quality of green spaces, technical solutions that provide cooling effects like fountains/sprinklers, green roofs/facades or appropriate building materials, and architectural constructions and elements that provide shadow). These spatial strategies and measures are provided by corresponding regulation systems, that is, they are furthered by the composition and configuration of the ecological structure and surface hydrographic systems, the open space network and the mobility infrastructure. For those systems to fulfil their promise, the structure need to be according to particular principles: 1. coherence with the conditions of the ground, as e.g. topography affects surface temperature levels; 2. permeation of the urbanized landscape, as e.g. enclosure of sealed surfaces minimizes the effects of possible ventilation of air currents; 3. they need to be porous, as e.g. the provision of cool spaces should follow the everyday movement patterns of the population; 4. flexible to manage, as e.g. the ownership regimes of strategic places need to allow for easy manipulation, and 5. contingency with the overall adaptation strategies, as e.g. the performance of individual measures is impacted by the presence of overarching strategies.

Taking, thus, this line of thinking backwards, the organization of regulation systems according to corresponding principles allows them to act as infrastructures that function as risk mitigation/adaptation devices for heat stress. Similarly, the degree to which specific regulation systems are structured, according to principles that correspond to the necessary spatial functions to address risk from heat stress, signifies the limits/thresholds for the provision of risk mitigation/adaptation services. A further step is presented in *Figure 19* and *Figure 20*, which turns the Strategic and Structural profiles of the Metropolitan Area and the municipality of Lisbon into Spatial Adaptation Profiles, that is, a series of maps that illustrate the spaces where interventions towards cooling is deemed important. These act as baseline images and guideline maps to initiate heat mitigation and adaptation spatial planning, and act as the foundation upon which climate modelling will evaluate their performance in reference to heat regulation and heat stress management.

The two maps (*Figure 19* and *Figure 20*) illustrate the spatial organization of a network of spaces to be designed in order to allow the spatial extents (the AML and the Municipality of Lisbon, respectively) to mitigate and/or adapt to heat stress and higher temperatures. Both Spatial Adaptation Profiles are characterized by a suggested strengthening of the ecological structure (that is, green and blue spaces) along the major mobility infrastructure and surface hydrographic systems. This is in line with the climate modelling conducted so far and illustrated in the previous section. Modelling results showcase both the need for the design of corridors of vegetation and surface water that permeate an urbanized landscape, allowing for ventilation, and the need for the intensification of the vegetation of the buffer zones around roads of higher order (e.g., motorways) away from mere grasslands.

The imperative for the infusion of the spatial extents with larger amount of vegetation in general and, in particular, dense vegetation (i.e., grouped trees with large crowns) is showcased in the AML and the Municipality of Lisbon through an intensification of the ecological structure and a punctual retrofitting in areas of high built-up density. This concurs with the climate modelling of the previous section that sees the old city centre of Lisbon in need of cooling places which cannot follow the corresponding design envisioned for the newer parts of the city due to a relative lack of space. Both the strengthening of the ecological structure as well as the retrofitting of punctual cooling measures follow a hierarchical logic and are, thus, composed of a gradient between intense vegetation all the way to simple soil unsealing or permeable ground materials, according to the spatial conditions of the site.

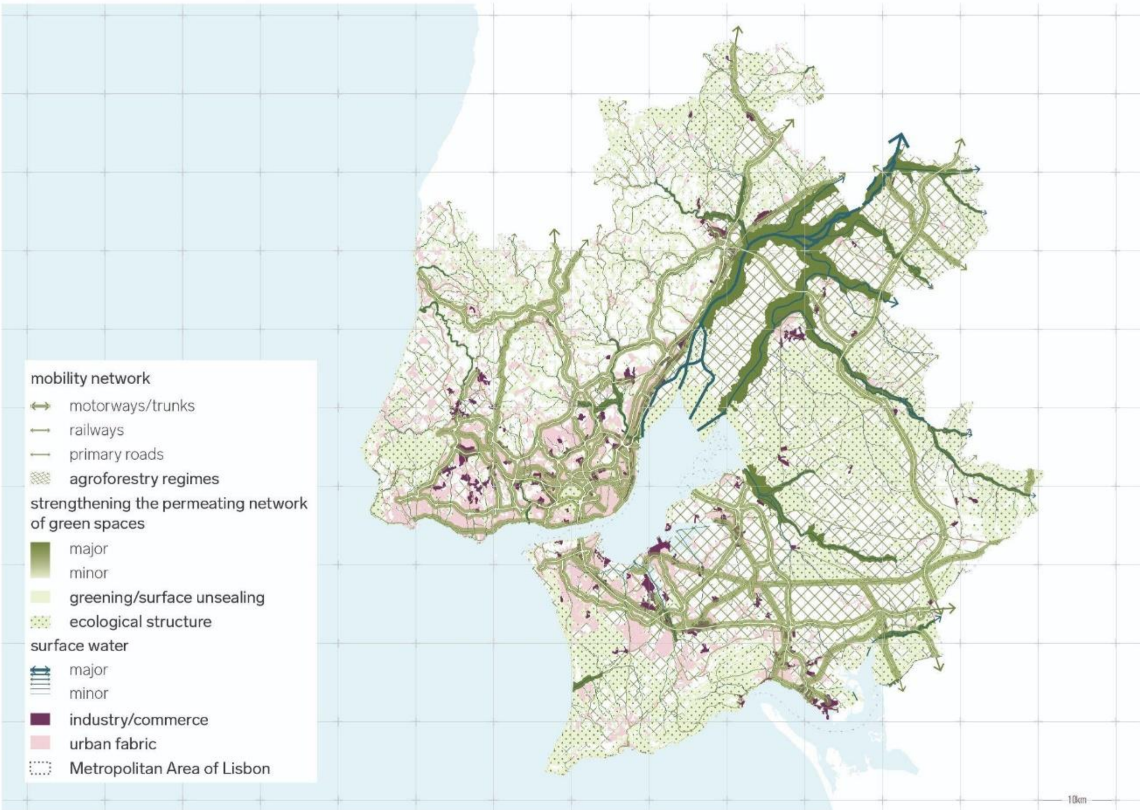

Figure 19: Spatial Adaptation Profile of the Lisbon Metropolitan Area for mitigation and/or adaptation to heat stress (BUUR PoS, 2023)

Figure 20: Spatial Adaptation Profile of the Municipality of Lisbon for mitigation and/or adaptation to heat stress (BUUR PoS, 2023)

The Spatial Adaptation Profiles are completed with the highlighting and selection of particularly critical places for heat stress mitigation and/or adaptation. These are: 1. the industrial and commercial areas which are usually characterized by a high number of sealed surfaces, and 2. specific spaces within the spatial extent that are along everyday citizen movement between residential and work environments, significantly far from other cool spaces and form a unity with places of public interest (e.g., public buildings) making them excellent candidates for emergency provision of cooling services.

3.4. Overshoot Proofing and stakeholder co-development process

3.4.1. Overshoot Proofing Application

During the first PROVIDE webinar (29 November 2022) all the 18 municipalities from the AML were invited to apply the OPM to their adaptation plans against heat, heat stress and/or temperature-related hazards. Municipalities were then invited to participate in a follow-up in-person facilitated workshop. A total of seven[8] municipalities and the AML office agreed to participate in this work (see Figure 21 below).

Each municipality and the AML contributed to the Overshoot Proofing by:

- Selecting one heat-related local adaptation plan (Table 1)
- Responding to the Overshoot Proofing questionnaire
- Taking part in a facilitated workshop (held on 22 March 2023)

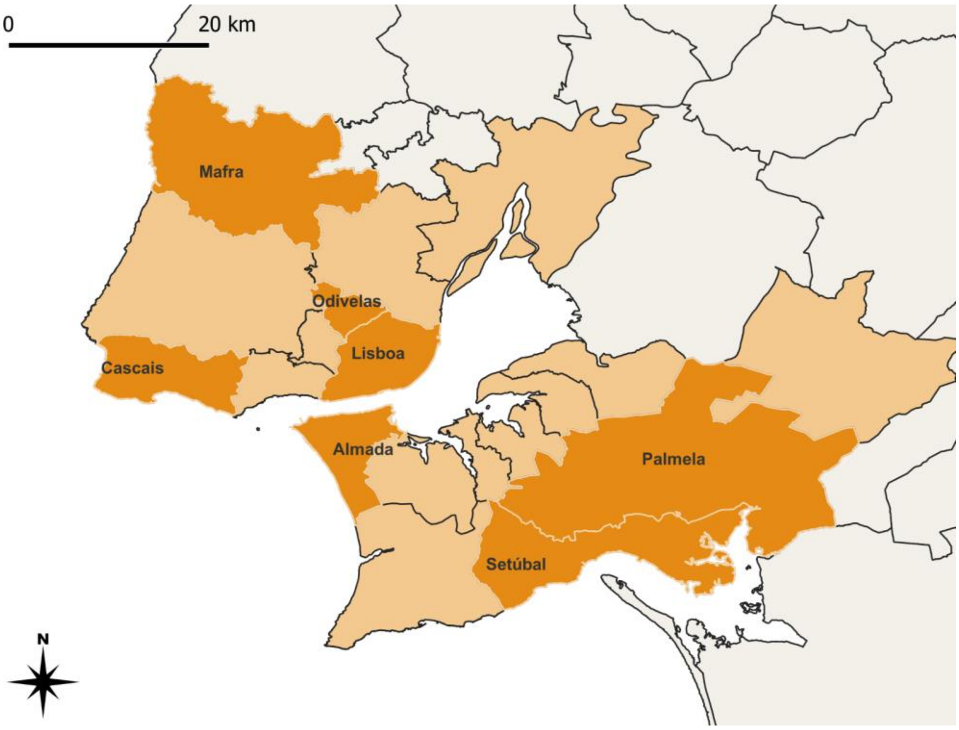

Figure 21: Lisbon Metropolitan Area (in light orange) and the municipalities that participated in the Overshoot Proofing of their heat-related strategies or plans (in dark orange)

The OPM questionnaire was developed and distributed online through the EU Survey platform[9] in both English and Portuguese. Each municipality was asked to provide one single reply to the questionnaire in relation to the selected strategy or plan, even if multiple practitioners were included in the analysis.

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[8] One additional municipality filled in the questionnaire but did not participate in the workshop, so its results are not included in this analysis.
[9] https://ec.europa.eu/eusurvey/home/welcome

Table 1: Municipalities that participated in the Overshoot Proofing (plus the AML office) with indication of its area, total population and the strategy/plan that was selected for proofing

Municipality	Area (Km²)	Population (2021)[10]	Strategy / Plan proofed
Almada	70	177,268	Metropolitan Climate Change Adaptation Plan – Almada application (https://documentacao.aml.pt/wp-content/uploads/2023/06/ebook-climate-change-adaptation-plan-lisbon-metropolitan-area-1.pdf)
Cascais	97	214,158	Cascais Climate Change Adaptation Action Plan (https://ambiente.cascais.pt/sites/default/files/anexos/relatorio_adaptacao_final_low.pdf)
Lisboa	100	547,733	Lisbon Climate Action Plan 2030 (https://amensagem.pt/wp-content/uploads/2021/08/PAC_LISBOA_2030_Relatorio.pdf)
Mafra	292	86,521	Mafra Municipal Climate Change Adaptation to Strategy (https://www.cm-mafra.pt/cmmafra/uploads/writer_file/document/1555/emmac_mafra.pdf)
Odivelas	27	148,058	Odivelas Human Health Seasonal Contingency Plan – Summer Season
Palmela	465	68,856	Palmela Local Climate Change Adaptation Plan (http://www.plaac.ena.com.pt/db/documentos/848.1.3.63c51a6190523.pdf)
Lisbon Metropolitan Area (AML)	3001	2,871,133	Metropolitan Climate Change Adaptation Plan (https://documentacao.aml.pt/wp-content/uploads/2023/06/ebook-climate-change-adaptation-plan-lisbon-metropolitan-area-1.pdf)

Invitations to the facilitated workshop were sent out by the PROVIDE FC.ID team as a follow-up to the municipalities' application of the OPM. The facilitated workshop was held in-person on the 22 March 2023 at the Faculty of Sciences - University of Lisbon (see Photo 5 on the following page), lasted for four hours and was supported and moderated by members of the PROVIDE FC.ID team. An experienced researcher in the theme acted as facilitator and guided the stakeholder's discussion, while two observers were taking notes and recording the discussion for analysis after the workshop. There was a total of eight participants, from six municipalities, plus the AML office. The meeting was held in Portuguese, including the presentations. The facilitated workshop intended to assess the adaptation plans/strategies of the AML under the Overshoot Proofing concept and discuss with adaptation practitioners a predetermined set of PROVIDE objectives, namely:

[10] https://www.aml.pt/municipios/

1. Assess if the municipal adaptation plans/strategies consider scenarios of overshoot, reversible impacts and critical thresholds to adaptation.
2. Identify and evaluate the practitioners' understanding of the concept of critical thresholds (including thresholds after a 1.5 ℃ overshoot or socio-ecological ir/reversible impacts).
3. Identify which (if any) changes may occur in priorities and/or timeframes of selected adaptation measures, when considering reversible impacts after a 1.5℃ overshoot.

The results of the OPM application to the policies described above are presented in the following section.

Photo 5: Facilitated workshop with AML adaptation practitioners at the Faculty of Sciences - University of Lisbon © Ricardo Encarnação Coelho

3.4.2. Results

There was a high variation in the type of adaptation strategy proofed (e.g., civil protection plans, municipal climate change adaptation actions or empirical study of climatic hazards), the timeframe for the implementation of adaptation actions (e.g., short, medium or long) and the priorities attributed to each adaptation action. Table 2 on the following page presents a summary of results from the application of the OPM in the AML and selected municipalities.

Table 2: Summary results from the application of the Overshoot Proofing Methodology in the AML Iconic City

Indicator (questions)	Almada	Cascais	Lisboa	Mafra	Palmela	Odivelas	AML	Comments
Global warming scenarios of 1.5 °C, 2 °C and 3 °C: 1. Does the adaptation policy assess different global warming scenarios?	1	4	4	4	4	1	4	**Most plans use multiple scenarios to select and prioritize adaptation.** Five out of seven stated their plans analyse multiple scenarios, including those going above the Paris Agreement thresholds, and use these scenarios to select and prioritize adaptation options. The two cases that scored 1, relate to a plan that is at metropolitan scale with only adaptation options analysed at municipal level (Almada) and another that is a health sector plan, which does not use scenarios (Odivelas). During the workshop it became clear that the **connection between choice of options and scenarios is not systematic.** Participants attribute this to the nature of the policies analysed that require choosing options that are generic in nature so the plan can be easily adopted politically (e.g., no detailed implementation costs or environmental impact assessments required).
Thresholds and limits: 2. Does the policy identify specific changes caused by climate change?	4	4	2	4	4	2	4	**Most plans analyse changes that are clearly connected with climate change and develop adaptation options to specifically respond to such changes.** Five in seven agree that their policies identify many specific changes to be tackled through adaptation with only two (Lisbon and Odivelas) acknowledging that only some of the changes identified are actually covered by their chosen options. In the workshop participants further added that the type of policy analysed can dictate the number and specificity of the measures proposed (e.g., the Odivelas policy is a contingency plan for health, so no adaptation options were identified).

Indicator (questions)	Almada	Cascais	Lisboa	Mafra	Palmela	Odivelas	AML	Comments
3. Does the policy identify thresholds and/or limits?	0	2	2	4	4	0	3	**Risk thresholds and adaptation limits are by far the least understood concepts, and those least used in the policies**. This indicator presented a wide spread of responses, from municipalities that did not assess thresholds and limits at all (Almada and Odivelas) to those that do a comprehensive analysis of all thresholds and limits affecting the system and use them to set up adaptation (Mafra and Palmela). Overall, the workshop consensus was that **when practitioners have the perception of a given risk threshold or limit to adaptation they try to assess and connect them to specific options.** However, often that perception is non existing (or not studied during the policy cycle), so they can go easily unnoticed (or under analysed). All participants acknowledged that **it is very challenging to establish critical thresholds and to effectively assess the impact of actions taken to address them**. Moreover, thresholds are typically not only based on empirical evidence, but also on social and political perspectives and expectations. A proper definition of thresholds could influence changes in emergency infrastructure (e.g., use of shelters during heatwaves)
Compound events: 4. Have multiple climatic and non-climatic risks which could particularly affect the systems related to the adaptation policy been considered?	0	1	4	4	4	2	4	**The concept of compound events seems to be well understood, but its study is not standard practice across the AML area**. Half of the respondents indicate that a comprehensive analysis of compound events was made in their policy and that it influenced the proposed adaptation options. However, the other half state that even when some of those events are assessed, they are not usually reflected in the options proposed.
Impact un/avoidability: 5. Are un/avoidable impacts identified in the policy?	2	3	2	4	4	0	4	**Impact un/avoidability is not typically assessed although awareness to the concept emerges.** Only three out of seven respondents refer that long-term and unavoidable impacts are comprehensively assessed in their policies and that planning objectives are tailored to the nature of the impacts included. All others either assess impacts un/avoidability but do not include long term objectives, or do not assess them at all. During the workshop, practitioners acknowledged that irreversibility is a sensitive concept mostly used in an ad-hoc perspective, sometimes helping to shape the final version of the proposed options (e.g., dropping options against unavoidable risks). Scientific assessments supporting the policies often do not include this type of analysis.

Indicator (questions)	Almada	Cascais	Lisboa	Mafra	Palmela	Odivelas	AML	Comments
Impact ir/reversibility: 6. Have you considered a potential overshoot scenario of 1.5°C global warming in your adaptation planning?	0	1	1	1	4	1	4	**The understanding of a potential overshoot is not fully applied to the adaptation planning by practitioners.** Only two of seven participants confirm that the impacts of overshoot scenarios (n.b. trajectories of overshoot) are specifically assessed and are considered when planning adaptation. During the workshop it emerged that the concept is not well understood, with participants acknowledging that the definition was not entirely clear. Replies span between those that understood the question as the ability of the plan to help achieve the 1.5ºC goal, and those that connected the notion of reversibility to the risks and vulnerabilities assessed.
7. Have you thought about impact ir/reversibility after overshoot?	0	2	1	0	4	0	3	**The conceptual understanding of impact ir/reversibility after overshoot is new and not well understood by practitioners.** Only one respondent asserts that a comprehensive assessment on ir/reversible impacts was undertaken, with results considered when planning adaptation. All others either do not include assessments of reversibility, or when they do, they do not routinely use it to plan adaptation (and do not reflect it in policy documents). When questioned if the priority and / or timeframe of their actions would change in case of potential impact reversibility after overshoot, almost all participants responded that yes, it would change. **Participants generally agreed that they could change the priorities of currently proposed adaptation options, but that depends on expected impact and timeframe of application.** Until now, all risks were perceived as potentially irreversible, and to some extent as being unavoidable, but since this may change in the future, with overshoot trajectories, so could the option's urgency change.
Total score	**7**	**17**	**16**	**21**	**28**	**6**	**26**	

Overall, the overshoot proofed adaptation plans presented medium to high scores. The highest scores (4) occurred when considering multiple climate change scenarios (question 1), identifying specific changes caused by climatic changes (question 2) and assessing compound events (question 4). The lowest scores (0 and 1) occurred when assessing limits and thresholds (question 3) and the concepts of overshoot and impact ir/reversibility (questions 6 and 7).

Identification of critical thresholds

Participants recognized the importance of addressing the concept of thresholds, as highlighted by the IPCC report AR6. High-priority and urgent measures need to be considered in the adaptation plans, considering the risks and vulnerabilities associated with climate change impacts. Therefore, participants were asked to identify any thresholds that could be used to increase the specificity of the options and measures in their adaptation plans and that could be added to future versions of the Climate Risk Dashboard. This result will feed into the next steps of the PROVIDE project, especially for the Climate Risk Dashboard development.

A proper definition of thresholds for these indicators could influence changes in emergency infrastructure, such as the use of shelters during heatwaves, as well as providing tracking for their usage frequency. Civil Protection agencies collect and analyse public health data that can be useful to better understand the effects of climate change on human health. However, this information can be challenging to obtain at the municipal level. For example, to address the increasing risks of heat waves, municipalities are creating refuge areas in parks, wooded areas and infrastructures with cooler envelopes or refrigeration such as gymnasiums, schools, and churches. However, currently, there are no established thresholds for when these refuge areas should be utilized, and their size and capacity are not yet determined. Participants suggested that there are limits for extreme temperatures defined in municipal civil protection guidelines, e.g., those already used as a reference by health centres, and that these could be useful for defining thresholds for refuge areas. Additional work on this topic is expected to be carried out under the next steps in the PROVIDE project.

Does adaptation change under reversible impacts?

When questioned if the priority and/or timeframe of their actions/measures would change in case of potential impact reversibility after a global (or local) overshoot, almost all participants responded that yes, it would change.

Participants generally agreed that it would potentially make sense to change the priorities of the currently proposed adaptation options and measures, but that would depend on the expected impact and the timeframe of application. Knowing the 'no return points' (N.B. thresholds) and the stakes involved (e.g., biodiversity or human lives) would be essential if changes in the priority of options are considered. One participant mentioned that changing application timeframes of existing priorities would be more likely than changing existing priorities (e.g., taking out options or measures from a plan and replacing it with others).

Participants in general expressed concerns about irreversibility because until now, all risks were perceived as potentially irreversible, and to some extent an unavoidable risk. This is particularly evident regarding the impacts of heat waves on various sectors, including health (mortality/morbidity) and infrastructure (damage to historical buildings). The relationship between heat waves and their effects on hospital admissions is a significant and relevant topic of discussion among climate change practitioners.

One of the critical challenges we can face in the future is the irreversible loss of species from municipal territory, such as the iconic cork oak. This loss not only has ecological implications but also signifies a matter of scarcity of cork resources, which is extremely relevant for the economy. Therefore, it is imperative to develop future plans and strategies that prioritize essential needs and minimize resource-intensive requests (financing measures), so that we can effectively focus on addressing the most pressing issues rather than constantly struggle to secure funding.

It was noticed that when discussing scenarios where we exceed the limits of sustainable resource use, there is a tendency to use language that frames it as "losing" something. Additionally, the urgency and timeframe for implementing measures to address overshoot should not be overlooked or delayed.

3.5. Reflections on the co-development process

Overall, participants suggested that current adaptation planning (i.e., options, measures and actions) was not related directly to specific thresholds. However, they also mentioned that in their view this is something already starting to emerge in discussions around adaptation planning and decision-making processes. Some municipalities are currently updating their adaptation plans and continuing the engagement with the PROVIDE team would be beneficial[11].

[11] An additional stakeholder's meeting was held on 6 November 6, 2023. In this meeting the results of the work carried out so far were presented and adaptation to overshoot scenarios was discussed. Outcomes of these meeting will be further explored in the upcoming deliverable 4.3.

4. Upper Indus Basin and Islamabad, Pakistan

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4.1. Context and reference

The Hindukush-Karakaram-Himalayan (HKH) region is crowned with the world's largest non-polar ice reserves, enriching ten major Asian river systems and nourishing four global biodiversity hotspots. With its extensive network of transboundary glaciers, rivers and valleys, the HKH region offers a unique vantage point for comprehending the interplay between changing climate dynamics and their multifaceted impacts. The Upper Indus Basin (UIB), nestled within the majestic peaks of Hindukush-Karakaram-Himalayan range, expands over 164,867 km2 in the northern part of South Asia, with almost 25000 km2 of glaciated area and over 17000 individual glaciers in the catchment. Most of the part of this basin falls within the geographical boundaries of Pakistan. The Indus River, originating in the UIB and flowing through Pakistan, is mainly fed by snow and glacier melt. It is a critical source of freshwater for millions of people downstream, and a crucial resource to the country's economy by sustaining the agriculture sector, which is the primary revenue generator. The Indus River, with its tributaries, also supports hydropower production, domestic and industrial water consumption, and vital wildlife.

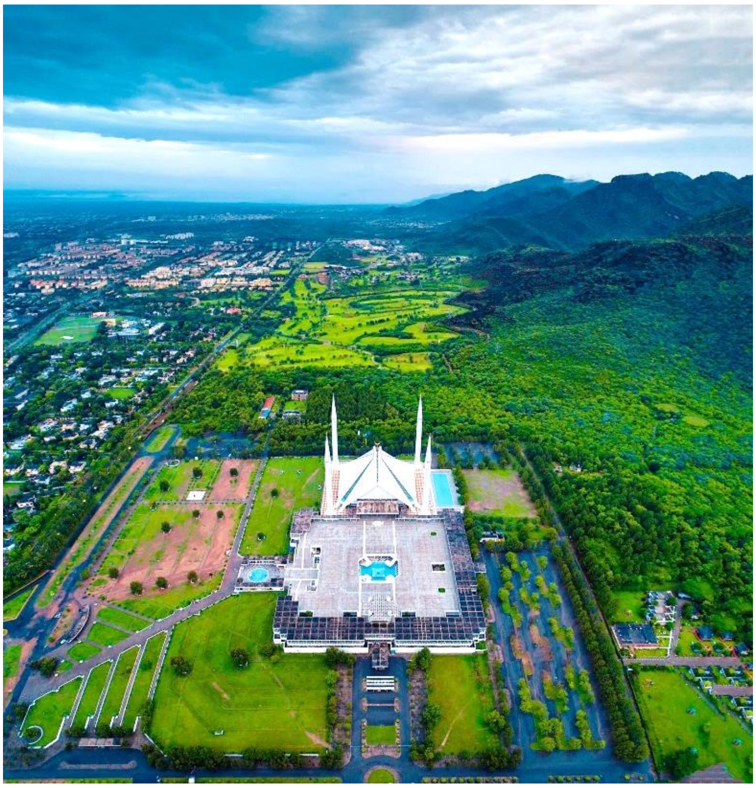

Photo 6: City of Islamabad, Pakistan © Hanan Khaleeq

However, with the rising global temperatures, the delicate balance that sustains the basin's ecology and supports local communities is increasingly at risk. Rapid glacial retreat, altered precipitation patterns, extreme heat, and ecological disturbances, even at current warming level, expose the country to several climate hazards - including Glacial

Lake Outburst Floods (GLOFs), avalanches, landslides, floods, heatwaves, droughts, forest fires, cyclones etc. Severe heat and water scarcity from fluctuating water resources are linked to crop failure, low yield and other agricultural losses, posing dire threats to national economic growth and food security. Furthermore, the region is not immune to the impacts of sea level rise, occasionally experiencing tropical cyclones. Beyond economic, human and biodiversity losses, these climate extremes notably impact cultural and religious practices, contributing to non-economic losses. All these factors contribute to the region's vulnerability to climate change, consequently impacting the livelihood and survivability of the inhabitants.

Extreme heat events are the major source of concern for the urban setting in the region, including the capital city of Islamabad. This climatically humid subtropical city is the centre for administrative, and diplomatic activities of Pakistan. With demographic changes, the previously planned city is growing unregulated leading to increased construction of concrete structures. This change in the city's canvas is not blending well with the rising temperature and frequent heat waves, resulting in heat stress affecting human survival. Furthermore, the impact is intensified as Urban Heat Island Impact comes into play. The vegetated and free spaces in the city are decreasing while the built structures are increasing. Consequently, increased solar radiation entrapment in the city's built profile is warming the centres more than the suburbs.

The region overall has low adaptive capacity, influenced by several constraining factors. The UIB is warming at a higher rate than the global average, with increased frequency, intensity, and duration of climate extreme events, threatening to push both human communities and ecosystems to the limits of their adaptive capacity. Even at 1.5°C warming, the magnitude and complexity of these hazards might cross several tipping points, resulting in irreversible and severe impacts. The complex climatic and geopolitical nature of the UIB, with insufficient resources, lack of expertise, uncertainty in institutional role, poor communication, fragmented approach, reactive and delayed policy formulation, present significant challenges to effective adaptation planning.

Most recent national policy documents also underscore various constraints limiting the progress in this regard. Pakistan's general climate response is directed by the National Climate Change Policy 2021 (NCCP) (Government of Pakistan 2021a) and the Nationally Determined Contributions 2021(NDCs) (Government of Pakistan 2021b), emphasizing the need of priority actions in the sectors of agriculture-food-water nexus and the urban infrastructure. There are some targeted interventions with adaptation component implemented by the collaboration of international donors, based on the initiatives of Nature-based Solutions (NbS through projects like Recharge Pakistan, Protected Areas Initiatives, Living Indus, and the Ten Billion Tree Tsunami already in place), Land Use Change & Forestry (REDD+ in place), and Community Infrastructure (Glacial Lake Outburst Flood (GLOF-II)). However, despite these efforts insufficient technical capacity remains a recurring challenge, urging the development of national capabilities in climate science, modelling, and technology for science driven policies. Furthermore, financial constraints coupled with poor governance and management, increase dependence on external assistance to strengthen climate resilience.

Pakistan's First Biennial Update Report provides sector wise insights into mitigation gaps and adaptation actions, emphasizing on a comprehensive GHG management strategy, and pinpoints the delay in policy formulation as a hindrance to progress in adaptation efforts, additional to common constraints identified in other policies (Government of Pakistan 2022). The Technology Needs Assessment for Climate Change Adaptation, promoted as a 'climate change adaptation tool' for climate resilient development, performs technology barrier analysis to identify obstacles to the adoption of new technologies. The major challenge highlighted is the low priority given to technology adoption by local government agencies due to high initial and operational costs, capacity issues, and a lack of supporting policies and regulations, such as land-use policies and zoning codes (Government of Pakistan 2016).

Very recently, the country has launched its long awaited very first National Adaptation Plan (NAP), which adds further to the list of many existing policies, but there still is a huge implementation gap to enhance the adaptive capacity and climate resilience. A discussion on NAP and other relevant policy documents is presented in section 4.4.1 of this report in the context of the application of the overshoot proofing methodology. Further details relevant to the climate change impacts and strategies for adaptation planning in Pakistan can be found in the previously published PROVIDE report on overshoot adaptation challenges.

4.2. Modelling approach to overshoot and adaptation

4.2.1. Urban Heat Stress Assessment using UrbClim model: Islamabad

High resolution heat modelling and the spatial analysis via UrbClim were severely hampered in Islamabad by the lack of correct detailed spatial data. However, through a local consultancy, detailed land use data was obtained, including an elevation model, for the sector E-11. These data were compiled by the Pakistani company Zi Informatika as part of a flood analysis they carried out in this neighbourhood. The PROVIDE research team purchased these data and decided to focus mainly on this sector in Islamabad for the high-resolution heat and adaptation research. The results of the flood analysis of Zi Informatika will also be included in the adaptation narrative.

In Islamabad, a heat stress exercise using the UrbClim model has been performed. A detailed set of heat stress indicators was calculated (listed in Annex 8.1). The modelling domain confines both the cities of Islamabad and Rawalpindi. Islamabad is a young city, built in the 1960s and characterized by a well-organized urban structure with modern planning. Its symmetric structure tries to blend natural elements with urban development. It is situated in the northern and eastern part of our modelling domain (Figure 22). Rawalpindi (located in the southern part of our modelling domain) is the fourth-most populated city in Pakistan and has grown more organically, with densely populated areas and narrow streets. Both cities are distinguishable from each other in Figure 22 by the thin black line.

Figure 22 further shows the average number of heat wave days per year (full definition can be found in Annex 8.1). Cities pop up as heatwave hotspots since they experience both high day- and night-time temperatures, as such offering limited cooling options compared to rural areas, which tend to cool down during the night. Generally, urban areas experience three times as much heatwave days compared to rural nearby areas in Islamabad/Rawalpindi. Furthermore, some distinct differences between both cities are visible. A clear contrast in the yearly number of heatwave days between Islamabad (15-20 heatwave days) and Rawalpindi (up to 30 heatwave days) is observed. This is related to the urban structure and becomes clear when looking at the insets of Figure 22 below. The city of Islamabad is structured in zones with a block structure, consisting mainly of mid-rise buildings surrounded by a high density of urban vegetation and trees, providing evaporative cooling, and reducing temperatures both during the day and the night (see inset 1, Figure 22). Larger green areas also pop up experiencing a significantly lower amount of heatwave days, stressing the importance of interconnected well-developed urban green features within a city. Rawalpindi on the other hand has a very high building density (inset 2, Figure 22). Very limited space is available for urban green vegetation and almost all open space is covered by sealed surfaces. These surfaces efficiently absorb solar radiation, storing heat, leading to high temperatures in both day and night-time during heatwaves.

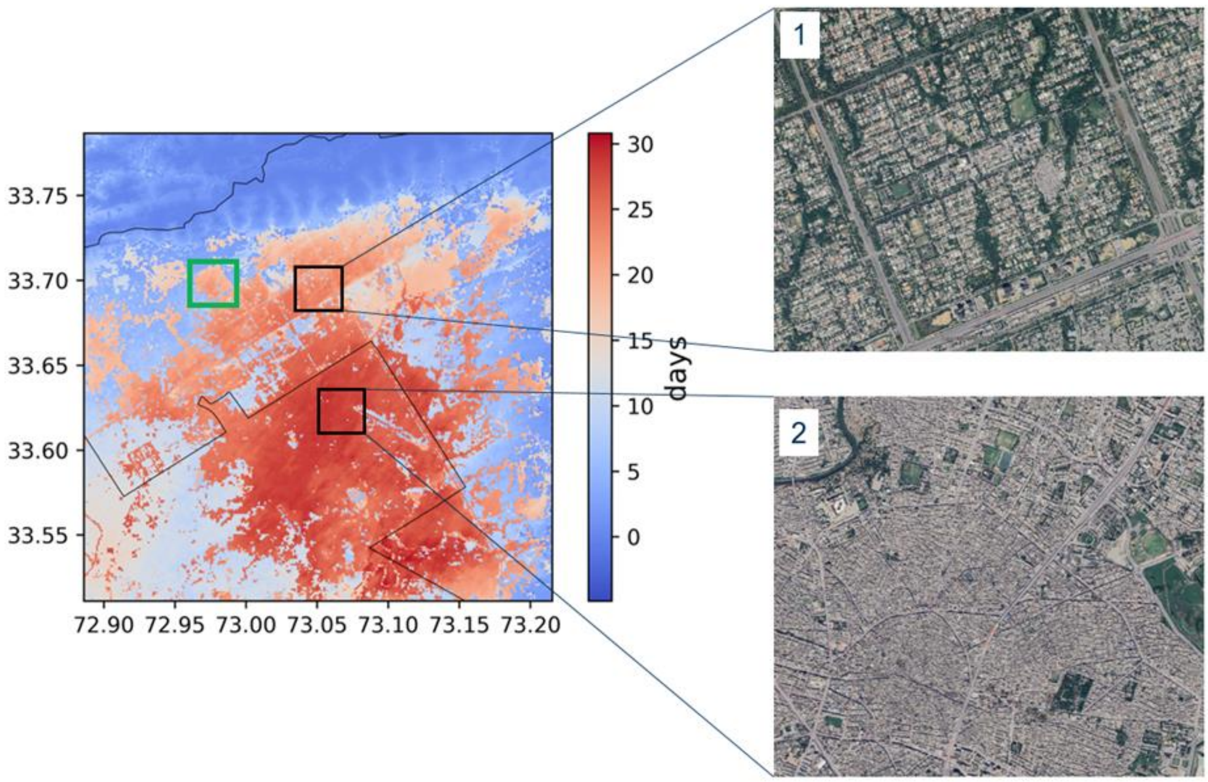

Figure 22: Average number of heatwave days in Islamabad (north) and Rawalpindi (south). Two insets are shown with their respective satellite images. The green square indicates the E-11 sector, for which a meter-scale analysis is executed

As mentioned above, detailed land cover information at meter-scale resolution is difficult to obtain for Islamabad, as no datasets on the matter are available. A meter-scale detailed assessment of heat stress modelling was therefore only executed for a small region, i.e., the E-11 sector in Islamabad (indicated by the green square on Figure 22 above) for which roads, building, tree contours and heights were obtained.

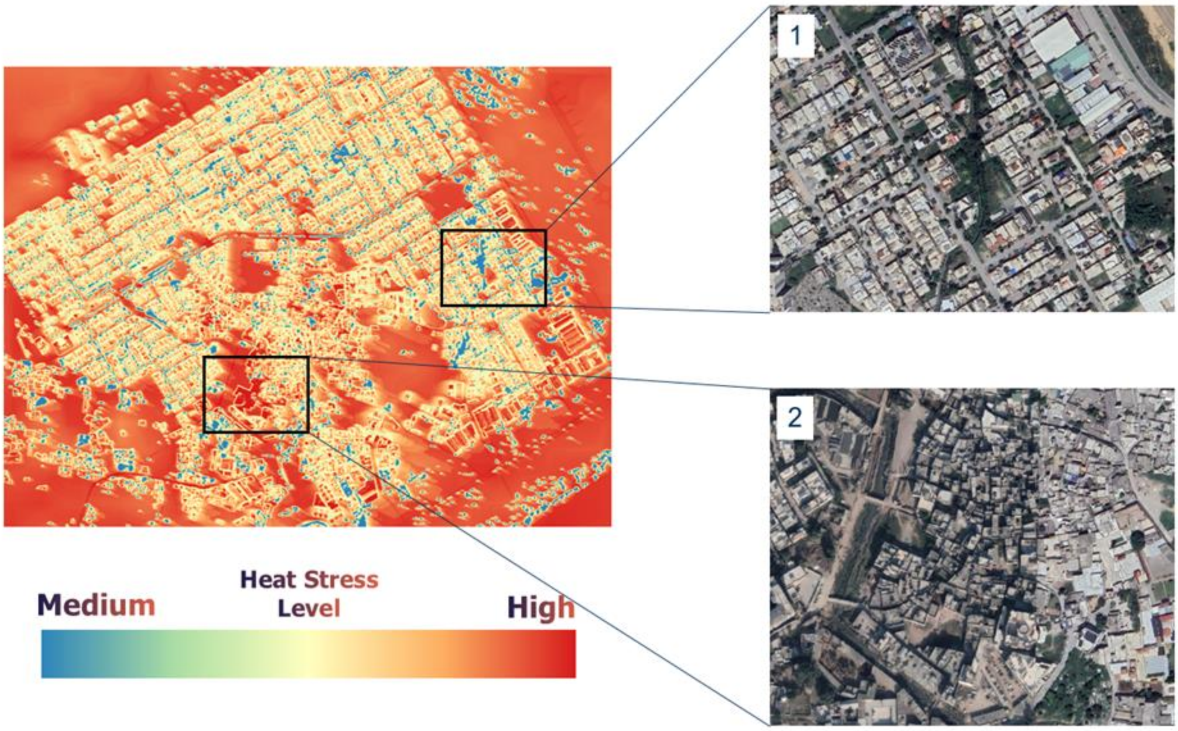

Figure 23: Heat stress levels at 1 m spatial resolution. Insets with different urban morphology are shown

Generally, open spaces and sealed surfaces exposed to direct sunlight experience highest heat stress levels (as visible in area 2, Figure 23 above). This area consists of a high amount of concrete, high building densities and limited areas for urban green. These surfaces absorb solar radiation and are responsible for an extra source of radiation, explaining the high heat stress levels that are attained at these locations, as shown in Figure 24 below.

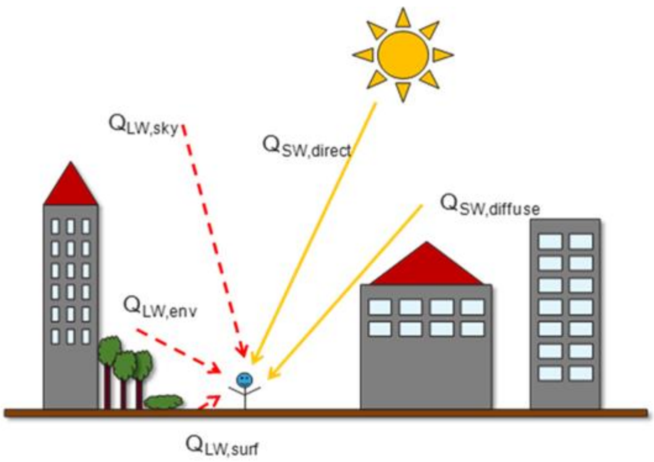

Figure 24: Sources of heat stress experienced by humans within a city

Apart from present-day, simulations for future climate have also been executed for CMIP6 scenarios. Future work will be done for the PROVIDE overshoot scenarios “Current Policies”, “Delayed Action” and “1.5℃ - Shifting Pathways” For each of the indicators listed in Annex 8.1, we provide decadal projections up to 2100. These maps, adapted for the PROVIDE scenarios, will provide the input for the PROVIDE dashboard. An example is given in Figure 25 below.

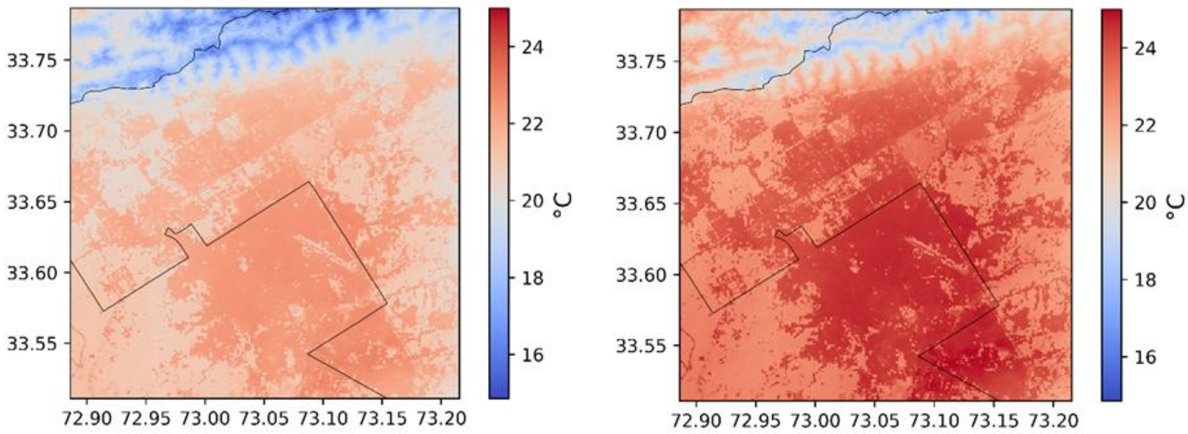

Figure 25: Annual mean temperature in present times (2011-2020; left) and by mid-century projected under the CMIP6 SSP5.8-5 (high emission) scenario (2041-2050; right)

4.2.2. Spatial Capacity Analysis for Adaptation to Heat Stress: Islamabad

As an introduction for the data received from Zi-Informatika, the context of sector E-11 is outlined below. Located in the north-eastern side of Islamabad, sector E-11, indicated by the black square in Figure 26 below, has a relatively flat topography with a slight decrease towards south.

Figure 26: The study area within Islamabad's green blue systems and the surroundings (left), and perspective view of pre-development drainage pattern (right)

Figure 26 further shows the site back in 2002 when the only existing built area was that of the historically developed Golra village. The drainage pattern is also made visible, and one can see the natural footprint of streams coloured in blue. Due to the hilly terrain (Margalla Hills) the drainage slopes are steeper in the north while towards south, where the channel slopes are milder, the drainage paths are wider.

While the Golra village was preserved without major layout changes (Figure 27 below), the stream network was extensively modified during development, leading to frequent flooding events which are mainly an effect of improperly designed drainage systems[12]. In contrast with the predevelopment map, the current map of the sector shows clearly that the natural flow paths were drastically reduced to reclaim land for construction.

The open space concept which was equally present in all the sectors developed in the 1960's was ignored when developing sector E-11. While the design focus of C.A. Doxiadis was on the open space structure, as a combination of natural landscape and public space that shaped and regulated the built form, the recent development is mainly shaped from the perspective of the built space. In addition, a logical subdivision of sector E-11 in sub-sectors with a residential or commercial character and a good distribution of public services was also not realized.

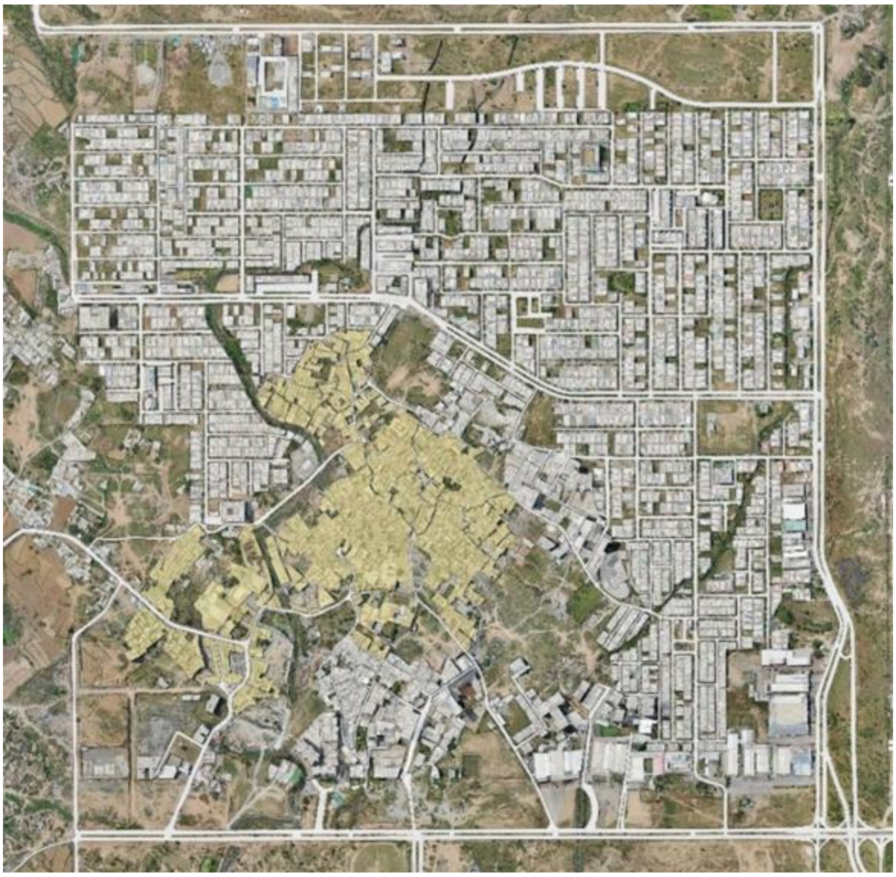

Figure 27: Golra village in light yellow and the recent development of sector E-11 in white

There is only a main road crossing sector E-11 from east to west while a north-south connection was not built, possibly due to the central location of Golra Village. The system of orthogonal local streets points neither at a visible street hierarchy nor at a developing major centrality. Most of the sub-sectors have a residential character (single-detached

[12]This assessment is based on the findings of an appraisal hydrological study conducted for the Capital Development Authority by Zi Informatika in 2022. The study (not published online) was conducted in response to a major flooding event in Sector E-11 of Islamabad on 28 July 2021 to critically appraise previous hydrological studies in the locality, present the findings and make recommendations to avoid such disasters in future. The results of the study were shared by Zi Informatika along with E-11 spatial data.

houses with one to three floors). Local centralities have developed spontaneously in building blocks with an increased density where commercial activities, services and public functions naturally settled in. The fact that in sector E-11 the density has been increased is definitely a positive aspect. However, densification of certain areas has to go hand in hand with certain conditions that have to be met (e.g., adequate public spaces and green areas, walkability, access to public transport, etc.).

As it can be seen in Figure 28 below, during a period of twenty years, the built up area in Islamabad increased more than five times while the areas covered with vegetation were constantly decreasing.[13] Bare soils which are a precursor of upcoming urban development have increased their surface which means that soil erosion has also been enhanced in the last two decades. All these factors will be considered for the analysis of spatial challenges and opportunities for adaptation under overshoot scenarios, in the next section.

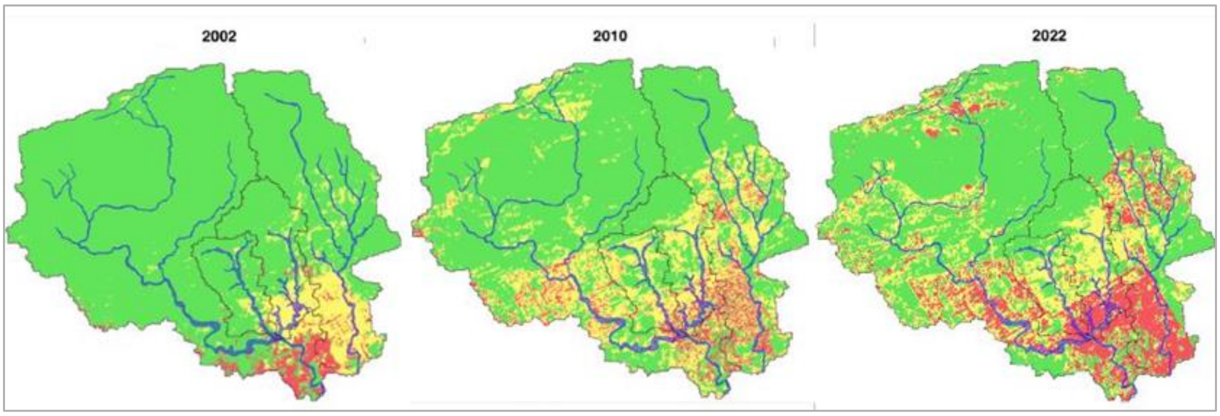

Figure 28: Spatial land-use change (2002/2010/2022): in yellow the bare soil, in red the built-up area, in green the vegetation area and in blue the streams right of way (Year 2002)

4.2.3. Urban Heat Impact Assessment using CLIMADA model: Islamabad

As described in the previous section, heat stress can be a serious challenge particularly in urban areas. In general, heat stress will be exacerbated in future warmer climates, which may have serious impacts on human health and well-being. To better understand these impacts, and in order to define efficient adaptation strategies, one needs to further consider the exposed population as well as their vulnerability. In this assessment using the CLIMADA model, differentiated impacts from a single hazard, i.e. heat during days and nights, on the health of the exposed population is considered. These serve as indicators for assessing different kinds of adaptation options. While during the day many behavioural adaptation options may be possible (e.g., changing working times, informing the population with weather warnings, or accessing shaded areas), for the night more individual and structural adaptation measures may be required (e.g., house isolation, air conditioning or ventilation corridors).

For the exposed population, the WorldPop dataset at 100m resolution, UN adjusted and constrained from the year 2020 is used. While it would be beneficial to include future

[13] Consultancy services of an expert hydrologist for the detailed appraisal/technical verification of the hydrological study submitted by PMCHS, E-11, Islamabad, Hydro-BIM by Zi Informatika (2022).

projection of population into the model for mitigation discussions, it is not clearly beneficial for adaptation option appraisal as discussed here. Indeed, much of the details in urban development are very sensitive to urban planning, district laws and general trends, which makes future projections difficult. Instead, general development scenarios might be considered as one of the various possible adaptation measures. Thus, for all times, the same static population dataset shown in Figure 29 (below) is used.

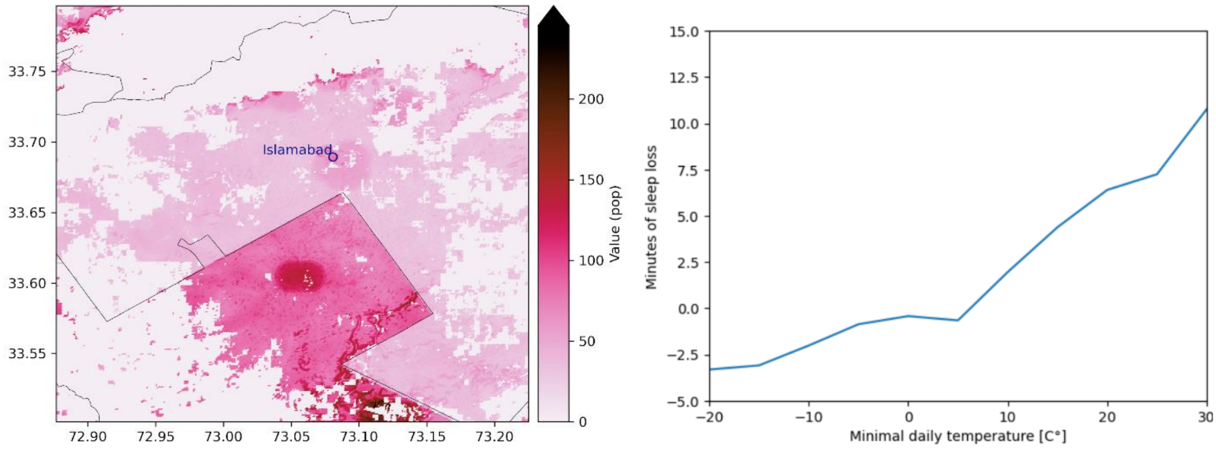

Figure 29: Population exposure distribution for Islamabad and Rawalpindi at 100m resolution as provided by worldpop (left), and impact function for the loss of minutes of sleep-in function of the minimum daily temperature (right)[14]

Two heat impacts were modelled explicitly as general proxies for the potential adverse effects of increased daily and nightly temperatures. During the night, most people are occupied with sleeping, which is known to be important for human health in general. Increased heat disrupts sleep and leads to a decrease in sleeping time. This effect is modelled by an impact function which relates the daily minimum temperature to the average loss in minutes of sleep based on the findings of Minor et al. (2022), as shown in Figure 29. For the day, the number of heatwave days per year is used. For Islamabad/Rawalpindi, a heatwave is defined as at least 3 consecutive days with maximum daily temperatures above the 90th percentile for that of the reference period (2011-2020).

Daily changes in the number of minutes of sleep loss for the study area were obtained using the CLIMADA framework (Aznar & Bresch 2019) by combining the daily minimum temperature time series computed with the UrbClim model for three climate scenarios, the population distribution exposures and the sleep loss impact function. Analogously, the yearly heatwave counts were used to obtain the number of people affected per year.

As shown in Figure 30 below, with rising temperatures the overall sleep loss in the study area increases, which may have effects on health, children education, worker productivity, and more. For the "Current Policies" scenario, the average increase in sleep loss is up to 12%, which could have important consequences on general health without adaptation.

[14] Note that negative values mean an increase in sleep with respect to the norm. Data taken from Minor et al. (2022).

For the “Delayed Action” and “1.5℃ – Shifting Pathways” scenarios the loss is at most 6%, which is half than under the “Current Policies” scenario for which the 6% threshold is crossed in 2050-2060 already. In contrast for the “1.5℃ – Shifting Pathways” scenario, the maximum is reached in 2030-2040, while for the “Delayed Action” scenario it is reached in 2040-2050. At the end of the century, the increase stabilizes at 3% and 5% respectively. Similarly, the number of heatwave days per person may increase by up to a staggering 140%, which could put vulnerable populations at acute health risk (Lüthi-Fairless et al. 2023). For the “1.5℃ – Shifting Pathways” and “Delayed Action” scenarios the maximum increase is less than 45 and 60%, respectively. For the former, the maximum is reached in 2020-2030, while for the latter it is in 2040-2060. At the end of the century, the increase stabilizes at 34% and 55% respectively.

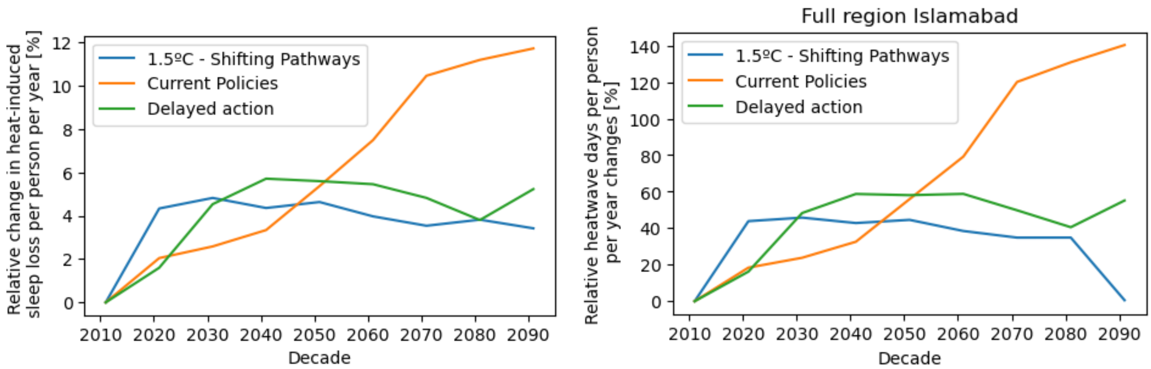

Figure 30: Relative change in the heat-induced sleep loss (left) and heatwave affected people (right) impacts per decade with respect to the reference period 2011-2020 for the three emission scenarios: “1.5℃ – Shifting Pathways”, “Current Policies”, and “Delayed Action” as provided by Urbclim (c.f. Section 2.2.1). The x-axis represents the beginning of the following decade

The distribution of the relative increase for both impacts is rather homogeneous over the whole region as shown in Figure 31 on the next page. In other words, despite the large differences in the population density, for instance between Islamabad and Rawalpindi, the dominating climate change signal leads to comparable relative increases in heat impacts. The heatwave days/person may increase by up to 300% under current policies over the most affected areas. On the other hand, the increase in sleep loss is at most 12% in the “Current Policies” scenario. This indicates that adaptations to extreme heatwaves are required in most of the areas, and adapting to the extreme daily maximum might be more urgent than adapting to the nightly temperatures.

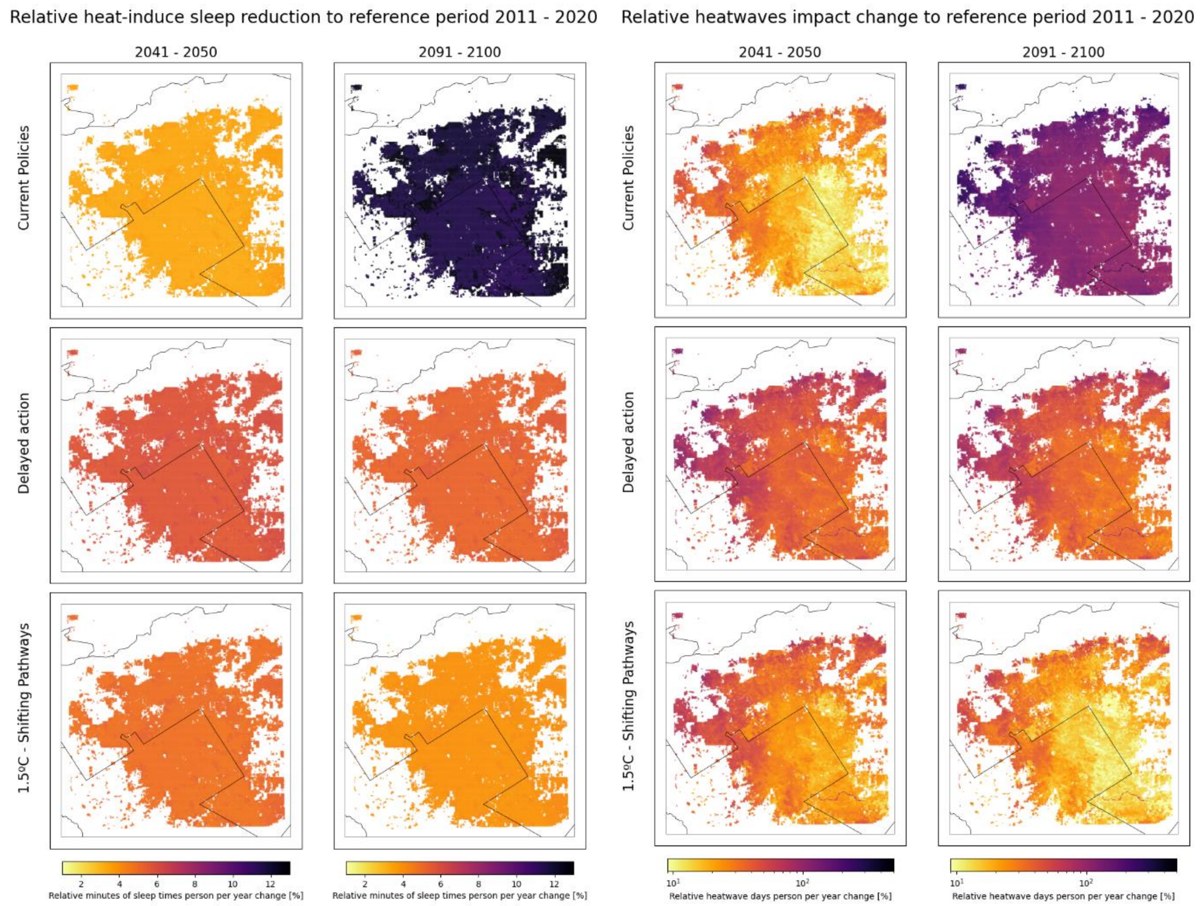

Figure 31: Relative change in heat-induced sleep loss (left) and heatwave affected people (right) for the decades 2041-2050 and 2091-2100 compared to the reference decade 2011-2020 for the three emission scenarios "Current Policies", "1.5°C – Shifting Pathways" and "Delayed Action" as provided by Urbclim (c.f. Section 2.2.21)

Note that the future projection of the daily urban heat is currently only available for the subset of the PROVIDE overshoot scenarios i.e. "Current Policies", "Delayed Action" and "1.5°C - Shifting Pathways". Data and maps for both types of impacts for all decades until 2100, with relative and absolute values, adapted for the PROVIDE scenarios, at different levels of (dis)-aggregation will be made available later as inputs for the PROVIDE dashboard.

4.2.4. Coupling of UBCWM with Open Global Glacier Model (OGGM): Projected Streamflow in the Upper Indus Basin

At the regional scale, the modelling task is focused on the application of UBCWM for the glaciers in the UIB. UBCWM is an extensively applied model in the UIB focusing on different sectors. Though it calculates glacier melt, the glacier area in the model remains unchanged. Earlier studies on the application of UBCWM for climate change assessment made use of near-hypothetical scenarios to represent changes in glacier area under different global warming futures. For example, in one of the studies, full spectrum glacier reduction scenarios have been employed, encompassing the range of 0%, 25%, 50%, 75% and 100% glacier area loss by the end of the 21st century, which led to the assessment of change in the streamflow in UIB catchments under different GHG emission scenarios (UlHasson et al. 2019).

For PROVIDE, an off-line coupling with the glacier mass balance model Open Global Glacier Model (OGGM) using CMIP6 data was developed, which simulates past and future glacier mass-balance, hence modulating the area of glaciers which then serves as one of the input parameters for the UBCWM. A decadal approach is employed by feeding in the glacial area information for each band of the UBCWM, and then running UBCWM for that particular decade by downscaling meteorological information from multiple General Circulation Models (GCMs), for which the OGGM was also executed (Table 3). It is worth noting that meteorological information from the GCMs is downscaled and bias corrected at the station level to force OGGM.

Table 3: Selected General Circulation Models (GCMs) and scenarios

Selected GCMs (based on OGGM)	Selected Scenarios (based on OGGM)
1: EC-Earth3 2: MPI-ESM1-2-HR 3: MRI-ESM2-0 4: INM-CM5-0 5: GFDL-ESM4	1: SSP126 2: SSP245 3: SSP585

Changes in Streamflow at Tarbela catchment

One of the most pressing concerns in the region is the alteration in the timing and amount of downstream water availability. The preliminary results from UBCWM presented in the Figure 32 below indicate that under the relatively low emission scenario of SSP126 (which takes the world roughly to 2°C by the end of the century) up to 20% reduction of flows at Tarbela catchment are projected in the peak summer months of July and August. A modest decrease in stream flows in the month of June is also observed during the second half of this century, while earlier and later summer months show an increase in the flows. This pattern more or less remains the same for the higher emission scenarios but intensifies. A high reduction in the flows in the peak summer months of July and August are projected for the SSP126 and SSP245 which are in the range of 20-40% and 60-80% respectively as we move towards the end of the century.

These projections paint a dire consequence for the agrarian economy of Pakistan. Agriculture sector accommodates more than 40% of the country's labour force and relies heavily on the melt water from UIB, which along with the monsoon have been supporting agriculture for centuries. Changes in the patterns of monsoon and water availability at present level of warming are already testing the adaptive capacity of this sector, which will be put under further stress for future warmings.

In the next step, the input variable for glacial area in the UIB, generated by OGGM using MESMAR data under PROVIDE, will be used to make future projection.

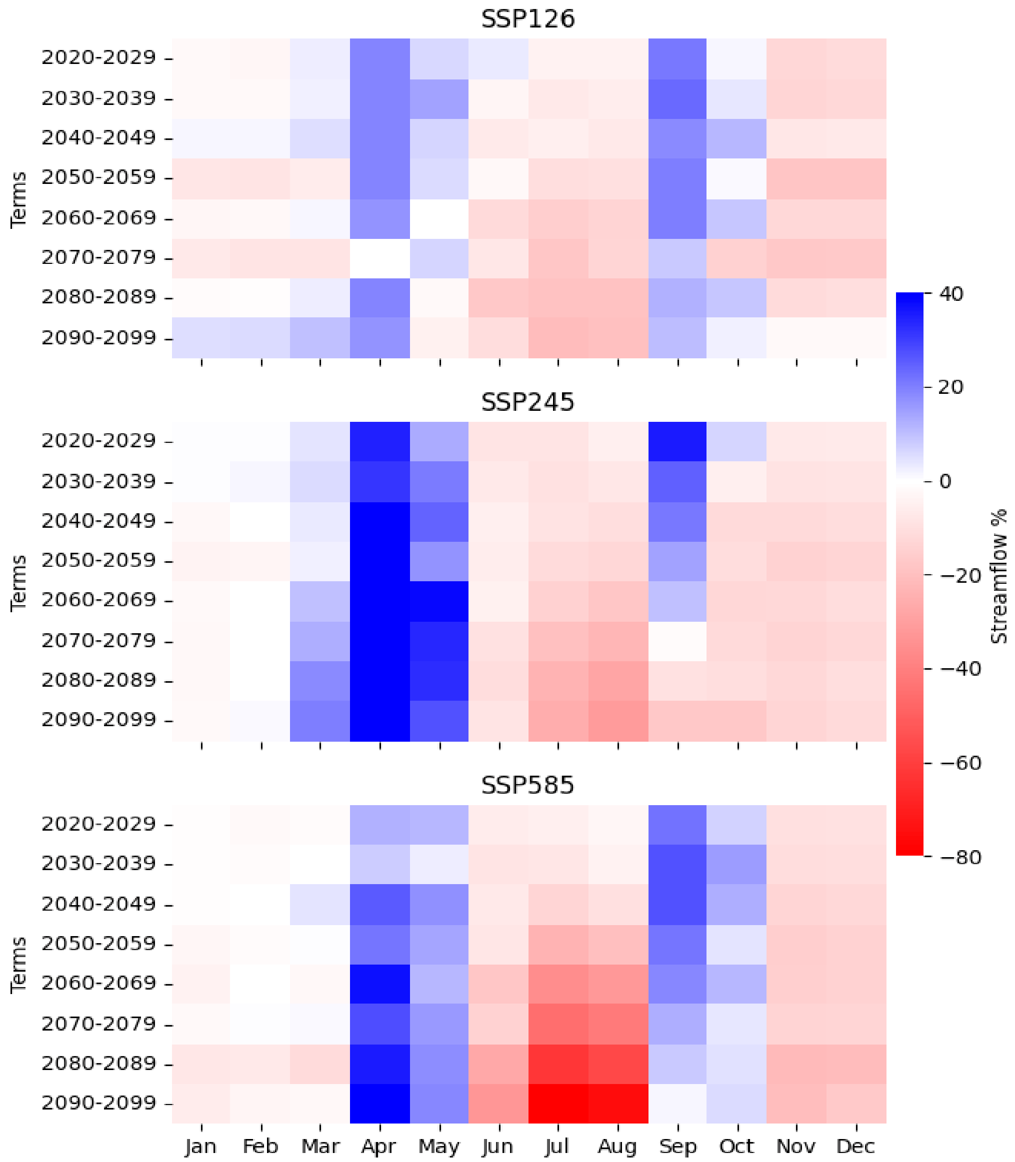

Figure 32: Percentage change in streamflow predicted by UBCWM (input parameters fine-tuned with OGGM data)

4.3. Spatial challenges and opportunities to overshoot adaptation

Detailed land cover information at meter-scale resolution allowed the meter-scale heat stress modelling to be realized for sector E-11, showing the impact of solar radiation on individual areas. The average daily heat stress levels for a clear-sky summer day (10th July 2020) which are depicted in Figure 33 below show that the high cooling potential of tree clusters has been radically diminished by minimizing the green corridors along the watercourses. Moreover, the still unbuilt areas in sector E-11 experience high heat stress levels due to the lack of high vegetation (aerial picture on top).

The large buildings built mainly on the south-east edge of the sector (bottom aerial picture) become a real hot spot during the summer days as the flat rooftops absorb and emit heat to a greater extent and the placement of the buildings in almost continuous strips make them act as a large built surface.

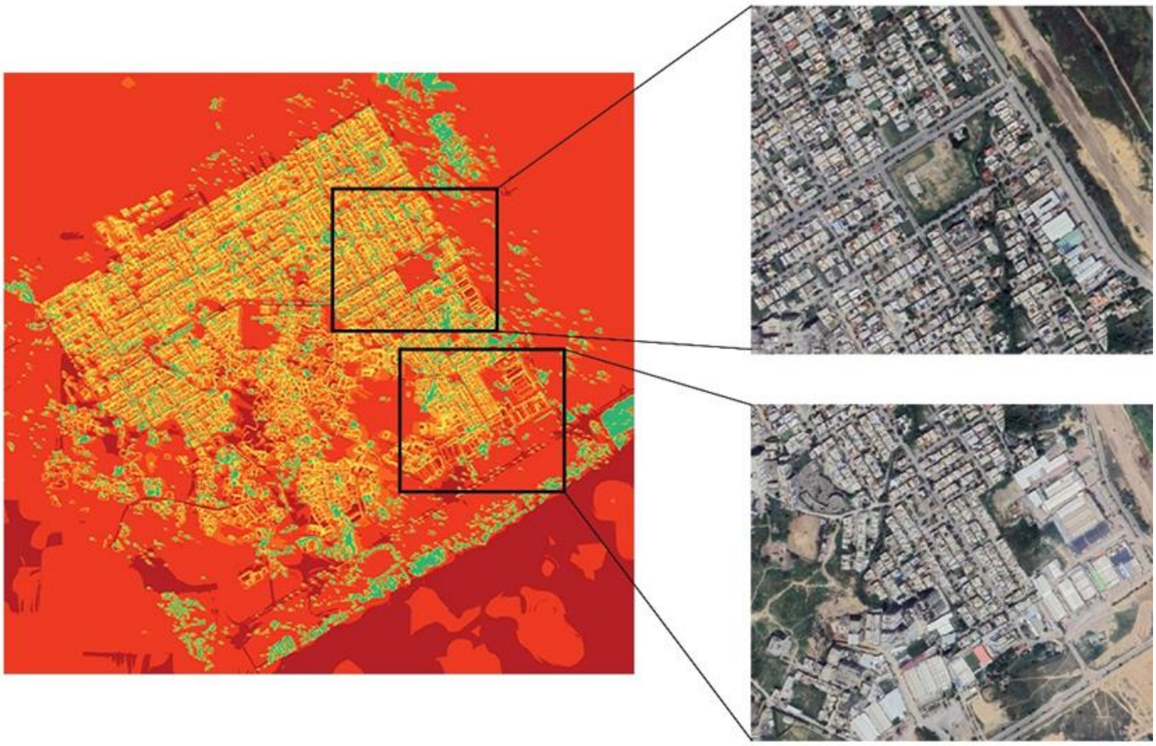

Figure 33: Average daily heat stress levels at 1 m spatial resolution and details of zones set under a high heat stress

To establish the current hydrological situation in sector E-11 and better understand the major flooding event that caused life and property losses in 2021, a study was conducted in 2022 by the consulting firm Zi Informatika, Islamabad. The extensive analysis has shown that the stream network was extensively modified during development. Many of the streams have been narrowed, straightened, and shifted, some were diverted into conduits and covered with a concrete slab while a number of bends and junctions were also introduced in the flow paths as shown in Figure 34 on the following page.

The final output of the flood routing model which was prepared for E-11 shows the simulation outcome for the 100-year return period flooding (see Figure 35 below). The flooded blue areas show that a 100-year return period flooding will impact many more areas than the event in 2021. The zoom-in pictures clearly show that wherever natural streams have been diverted into narrow conduits, backwater curves are created by these structural modifications and upstream areas are extensively flooded.

Adding to the narrow width of the drain provided by the builders in certain areas, property encroachment in the drainage path has also been observed, causing culverts to overflow their banks. In the light of this study, it's becoming evident that the incidents of July 2021 are to a great extent a consequence of planning flaws and not necessarily an outcome of climate change.

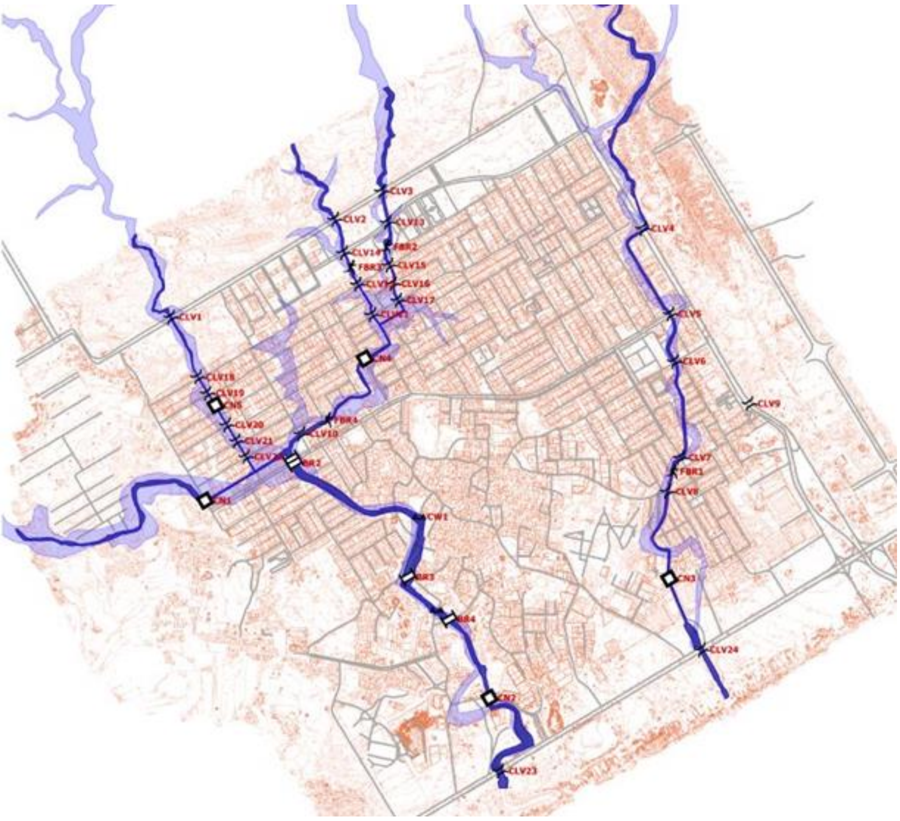

Figure 34: Natural waterways (streams right of way 2000) and the superimposed drainage system (2022)

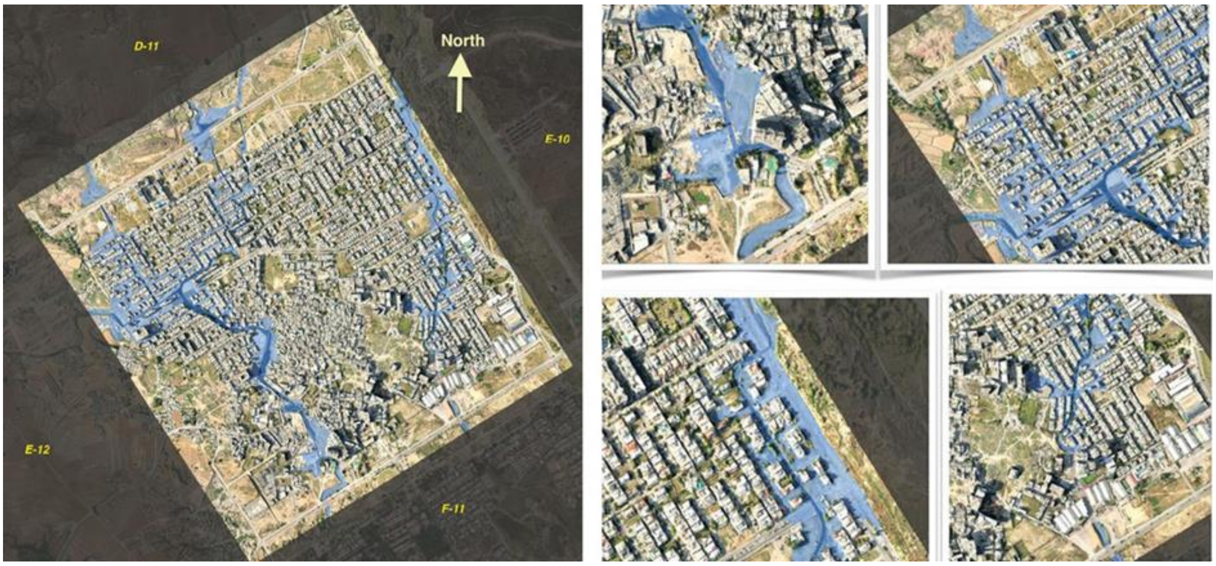

Figure 35: Flood routing model and examples of flooded areas in sector E-11

In the next phase of the PROVIDE project we will be looking in detail into how spatial planning measures could lead to an improvement of the situation in sector E-11, both in terms of heat stress and flood management. Having to deal with an extensively developed area where many planning decisions have been already taken, will definitely be one of the main challenges. However, a bold approach to solving the urgent flooding issues could also result in huge opportunities regarding the transformation of sealed surfaces and open spaces into green buffers that provide as well for the water retention function. The restoration of natural drainage paths along with the possibility to create larger green corridors will be analysed and solutions will be developed for the areas where properties have encroached into the narrow streams.

In order to respond to heat stress, the quantity and quality of green spaces will be assessed, and solutions will be proposed to provide for cooling effects and more shadow. Moreover, spatial strategies and measures will be developed that will ensure a resilient way of building.

In a continued process of stakeholders' engagement, progress of the project at various stages is shared with the local stakeholders for further input and feed-back, so that the indigenous knowledge gets well reflected in the outputs.

4.4. Overshoot Proofing and stakeholder co-development process

In the second phase of the project, a webinar was held on 13 December 2022 to receive feedback from the stakeholders on the progress so far under the PROVIDE consortium. A series of presentations from relevant partners familiarized the stakeholders with the developmental process of the Overshoot Proofing Methodology (OPM), shared progress on heat stress maps using UrbClim and spatial structure profile for the city of Islamabad and highlighted the importance of these elements in adaptation planning, both at regional and urban scales. Lastly, the latest version of the PROVIDE dashboard was also presented. The stakeholders in attendance belonged to various public, private, and development sectors (details available under webinar report). To gauge further response, Weather and Climate Services (WCS) carried out online surveys and in person meetings with stakeholders in the following weeks. The concept of temperature overshoot beyond safe limits was explained to the stakeholders as most were not cognizant with the notion. The choice of policies to be overshoot proofed was also conveyed by the stakeholders. It was deemed suitable to include the recently published or updated policies/plans mentioning the current climatic challenges faced by the country.

During these meetings, the gaps in policy and implementation were highlighted. While policies may be ambitious, the absence of effective implementation hinders their ability to foster adaptive development. Keeping this in mind, it was also decided to engage with officials involved in ongoing adaptation projects in Pakistan, particularly those under the UIB, and apply the overshoot proofing methodology to these projects in the upcoming stakeholder engagement workshop/webinar. Pakistan has several large-scale projects in operation, despite not being directly derived from policy, and these can offer valuable insights into the dynamics of adaptive development and resilience to overshoot scenarios. Therefore, representatives from some of the selected adaptation projects were also invited to the second stakeholder workshop, held on 14th November 2023 (see Photo 7 on the next page).

Photo 7: Second stakeholder workshop in the Iconic City of Islamabad © Khadija Irfan

The second stakeholder engagement workshop was attended by representatives from government entities, development sector organizations, and public sector institutions (see workshop report for details). The focus of this event remained an in-depth elucidation of the OPM, with emphasis on its application to various policies and projects operative within Pakistan. The application of OPM to National Adaptation Plan (NAP) was presented as a case study, by the PROVIDE regional team, to garner better understanding of the concept and purpose of the OPM.[15]

The policies selected by the participants for OPM application encompassed critical domains, such as the National Climate Change Policy, the National Disaster Risk Reduction Policy, the Food Security Policy, the National Water Policy and the National Summer Emergencies Plan. Feedback from participants underscored a shared concern: the prevailing inadequacy in regional and urban adaptation planning to systematically identify and address all hazards and associated risks threatening the sector. It was emphasized that current policies and plans are mainly based on resilience against previously faced threats, such as floods and droughts, often neglecting future impacts considered under different warming scenarios, such as the exceedance of critical human survivability temperature threshold and its impact on the population. Despite widespread awareness of climate-induced threats across economic sectors, there is a notable gap in aligning adaptation strategies with future projections under warming scenarios, identifying thresholds, and addressing both avoidable and unavoidable impacts, including those of an irreversible nature. Hence, results of OPM application to the above-mentioned policies were like those obtained from OPM application to NAP.

Participants' discussion also highlighted that the translation of formulated policies into tangible on-ground interventions faces substantial challenges. A primary obstacle is the high financial cost associated with implementation, compounded by difficulties in

[15] The revised version of OPM, that was updated after feedback from all IRs, was explained and applied to policies/plans during the workshop.

accessing international finance. The deficiency of pertinent adaptation-related knowledge within various governmental departments was conveyed as another contributing factor that further complicates the effective implementation of these policies.

Additionally, the local PROVIDE team also conducted two different sets of surveys/interviews, one to get feedback from practitioners on local adaptation planning as co-development process of the Climate Risk Dashboard and another on adaptation to urban heat in the city of Islamabad to inform the design of quantitative relationships (impact function) between extreme heat and societal impacts using local expert knowledge, as further input for UrbClim modelling.

4.4.1. Overshoot Proofing application

Due to the escalating heat stress in both regional and urban contexts, application of OPM to heat related plans would have been highly relevant. While national media and international reports referred to a national-level Heat Action Plan (HAP), no official publication of such a plan has occurred thus far (Amnesty International 2023). Relevant government sector departments including the Ministry of Climate Change and Environmental Coordination, Pakistan Meteorological Department, Environment Protection Agency, National Disaster Management Authority, etc. were contacted via phone and met in-person to gain information on the potential release date of the plan. However, none of the contacted departments were aware of the development or presence of such a plan. Some departments conveyed that a HAP for Pakistan has not yet been formed, although a provincial level HAP for Khyber Pakhtunkhwa from 2022 was updated very recently and the urban level plans for Karachi (2017) and Lahore (2022) do exist (Government of Khyber Pakhtunkhwa 2023, Government of Sindh 2017, The Urban Unit 2022). Hence, amidst the uncertainty regarding a national level HAP, the focus shifted to other relevant adaptation plans.[16]

The sectors considered

For the application of OPM, it was decided to consider holistic adaptation plans available in Pakistan, that also inform planning and development in UIB and Islamabad. Following policy/guiding documents were then selected after consultation with relevant stakeholders:

- The National Adaptation Plan (NAP, 2023), most recent adaptation guiding document for Pakistan and hence highly relevant.
- The Green Building Code (GBC, 2023), infrastructure guideline directly applicable to adaptation needs in urban built environment.

Methodology

To streamline the application of OPM for the selected policies, the concept and purpose of the process were communicated to the relevant stakeholders via email. Later, a

[16] During finalization of this report, it was found that National Disaster Management Authority also released a National Summer Emergencies Plan 2023, that was later considered for overshoot proofing during the second stakeholders engagement workshop on 14 November 2023.

document containing an introduction to the project and the OPM, was shared with the interested stakeholders. This document also included score-based indicators assessment and a glossary to explain unfamiliar terminology. The process then followed up a series of in person meetings with stakeholders during the summer, although not all of them participated in the OPM assessment exercise, however noteworthy information gathered during these discussions has been included in the report.

It was indicated that most of the policy makers are completely nescient about the idea of overshoot beyond 1.5°C, hence the existing strategies/policies did not account for overshoot or establish connections between adaptation needs and varying global warming levels. Nevertheless, stakeholders acknowledged that consideration of overshoot was highly pertinent to effective adaptation planning and implementation within the regional context.

In the case of the recently released National Adaptation Plan, it became apparent that much of the development of this widely celebrated document was facilitated by international consultants. Furthermore, the relevant stakeholders met thus far were not well aware of overshoot scenarios. Owing to these considerations, it was deemed appropriate for the UIB regional team to independently apply the OPM to the NAP and subsequently present it to stakeholders as a case study. Stakeholders could then get a clearer idea of the exercise of OPM application and would be able to extend it to other policies in the upcoming workshop.

For the Green Building Code, consultants directly involved in the development, from the Ministry of Climate Change, UN HABITAT and Pakistan Engineering Council, were met in person and briefed on the PROVIDE project, followed by explanation regarding Overshoot Proofing component and its importance. Stakeholders were conveyed the significance of their involvement as well as their response. The Overshoot Proofing was deemed as a discussion initiating exercise on the need of assessing overshoot implications in the region’s developmental planning.

The National Adaptation Plan (2023)

The National Adaptation Plan (NAP) for Pakistan was recently released in August 2023 following a deliberate process (Government of Pakistan 2023). The formation of NAP was clause under the Nationally Determined Contributions (NDCs) 2021 to develop a detailed adaptation strategy for the country. Developed amidst Pakistan's ongoing encounters with multiple climatic disasters, including compound events, the plan was deemed to be most current and attuned to evolving needs, making it suitable for the application of OPM.

For the governance and implementation of NAP at the federal level, Ministry of Climate Change and Environmental Conservation (MoCC&EC) is identified in the lead role, whereas Ministry of Planning, Development, and Special Initiatives (MoPD&SI) will act as the main coordinating body, liaising with various federal ministries and provincial departments.

The NAP document gauges the adaptive capacity of four priority sectors and proposes tailored adaptation interventions with short-, medium- and long-term objectives for each one of those. These mapped interventions depict a nascent stage that require further development through cross-sectoral collaborative action. The four priority areas include:

- Agriculture-Water Nexus, with sectoral context on Agricultural Land and Food System, Water Management for Irrigation, Livestock and Farmer-Level Challenges

- Natural Capital, providing sectoral context on Land and Ecosystem, Water and Air Pollution
- Urban Resilience, considering Urban Development, Municipal Services and Air Pollution sectoral contexts
- Human Capital; with Health, Education, and Labour-Economic Productivity sectors taken for context

The policy also broadly provides an assessment of climate change vulnerabilities across various sectors. In Agriculture-Water and Natural Capital areas, ecosystem degradations are highlighted as the major climatic impact that significantly reduces resource efficiency. Additionally, in livelihoods dependent on natural capital (crop production, fisheries, livestock etc) limited adoption of modern technology further impedes adaptation efforts in these sectors.

The main challenges highlighted for Urban Areas are increased migration and urban sprawl, further straining existent civic facilities. The unplanned development and informal construction, to harbour the population influx, makes these areas even more vulnerable to climatic effects such as Urban Heat Island and pluvial/fluvial flooding. The NAP underscores the absence of a unified land record system and inconsistent data which hamper effective land management practices under adaptation. In general, integration of Nature based Solutions, comprehensive Land management practices, and climate smart technologies are envisioned to strengthen urban resilience.

The suboptimal human capital indicators in the region can be attributed to its vulnerability to climate change. Climatic impacts influence, both directly and indirectly, human health, education, and subsequently affecting economic potential. The NAP seeks to integrate resilience components into relevant policies. It also emphasizes strengthening emergency response mechanisms and enhancing workforce capabilities to curtail the adverse effects of climate change on human capital development.

The proposed interventions draw from assessments by diverse contributors, including relevant government ministries, research institutions, technical experts, and sector specialists. However, due to technical and scientific capacity gaps, noted also in the National Climate Change Policy and Nationally Determined Contributions, many assessments were outsourced to consultants unfamiliar with the local context. Consequently, the recommended actions are often generic and lack local insights.

The Green Building Code (GBC)

This policy was selected for Overshoot Proofing as it provides insight into urban adaptation and infrastructure resilience to climate impacts. Since this involves long term investments, it is one of the critical sectors to be considered, especially for countries like Pakistan, already struggling with economic challenges. The code, (although not yet officially online) draws from the International Green Construction Code (Switch Asia 2022).

The GBC is one of the few sectoral plans devised in response to worsening climate change. While climate resilience is not the only agenda that encourages its development, it is one that holds due importance in its implementation. The stakeholders involved in its development include line ministries, development agencies, and federal regulatory authorities. EU SWITCH-Asia in collaboration with the Ministry of Climate Change, Pakistan Engineering Council, UN-Habitat, NED University, and International Code Council concluded the code formulation in early 2023.

Stakeholders conveyed that the varying and diverse climatic conditions throughout Pakistan, including the UIB, necessitated the development of these building guidelines for region-specific needs. For example, in Southern Punjab extreme heat poses significant threats while in Northern Pakistan, the floods, erratic snowfall patterns and Glacial Lake Outburst Flood events are major climatic issues. Therefore, each geographic area requires different building guidelines. These needs are addressed through recommendations on appropriate use of building materials, direction, and positioning of the building, landscaping etc. in the green building code which is developed following the standardized International Green Construction Code (IgCC-2018).

Furthermore, the improper building orientation and lack of insulation were highlighted as existing gaps in the prevalent infrastructure design. The orientation of the building should be south facing to minimize sunlight entering the building, hence preventing warming. In addition, insulation prevents absorption of heat from surroundings, especially during the day. The concrete structures absorb heat from sunlight and insulation provides a remedy to counter that, thus minimizing heat stress and diminishing Urban Heat Island (UHI) effect. Green rooftops covered with vegetation were highlighted as natural insulators. All these recommendations are included as building standards in the GBC.

The stakeholders conveyed the immediate need to include GBCs in the planned building designs to minimize the impact of worsening UHI effect. However, one of the key issues exacerbating the UHI effect is the unplanned expansion and the unregulated encroachment of buildings not only in Islamabad but also in UIB. This issue is not addressed in the GBC and is said to be included in the yet unpublished Urban Resilience Guidelines.

The results of OPM application on both the policies discussed above are presented in Table 4 as follows.

Table 4: Scorecard based assessment along with comments

Indicator (Relevant Questions)	**National Adaptation Plan 2023 (Regional-Adaptation)**	**Green Building Code 2023 (Urban-Infrastructure)**
Global warming scenarios of 1.5°C, 2°C and 3°C: Does the adaptation policy assess different global warming scenarios?	**Score**: 1 **Comment:** The plan does mention impacts of projected temperature rise on different sectors such as labour productivity and wheat yield, however, based on RCP4.5 or RCP8.5 projections. Hence, does not provide a realistic baseline for vulnerability assessment to inform policy development.	**Score**: 1 **Comment:** Global warming is one of the main drivers behind the need of the GBC. However, the code is not based on warming scenarios rather than currently identified impacts of global warming on buildings.
Thresholds and limits: Does the policy identify specific changes caused by climate change?	**Score**: 3 **Comment**: Sectors wise impacts especially in priority sectors are listed qualitatively in a broader sense but do not explicitly translate into the interventions proposed by National Adaptation Plan.	**Score**: 2 **Comment:** Yes, climate change is identified as a major cause of increasing Urban Heat Island effect which steered the need for certain code provisions such as building orientation and insulation.

Does the policy identify thresholds and/or limits?	**Score:** 1 **Comment:** Temperature threshold beyond which human productivity and survivability will be affected is noted. However, this assessment lacks accurate articulation e.g. inconsistent mention of dry/wet bulb temperature.	**Score:** 0 **Comment:** No thresholds identified
Compound events: Have multiple climatic and non-climatic risks which could particularly affect the systems related to the adaptation policy been considered?	**Score:** 2 **Comment:** Several risks that limit adaptation capacity have been identified. These include financial constraints, inequalities and parity, and predisposed vulnerability of populations. There is only a broader mention of compound events. Linkages between environmental and social risks are highlighted. For example, climatic events leading to loss of habitable land, population displacement, migration and conflict etc. However, these issues are identified but not specifically targeted through interventions.	**Score:** 3 **Comment:** The code renders good understanding of climatic and non-climatic factors such as economic viability of standardized construction. Directed by principles of sustainable development, the code prioritizes the use of recycled and reclaimed construction material. However, the guidelines primarily focus on building design and resource efficient construction rather than addressing socioeconomic risks and opportunities that may limit adaptation.
Impact un/avoidability: Are un/avoidable impacts identified in the policy?	**Score:** 1 **Comment:** There is some awareness on long term impacts but no assessment on un/avoidability of those impacts under adaptation.	**Score:** 1 **Comment:** No, un/avoidable impacts assessed. This is because these assessments are mainly a component of policy development. The codes are standardized provisions that only direct improved construction. The study of avoidable or unavoidable impact is beyond its scope. Threats such as Urban Heat Island effect and excessive flooding have been addressed to the extent of being recurrent but not defined as avoidable/unavoidable impacts.
Impact ir/reversibility: Have you considered a potential overshoot scenario of 1.5°C global warming in your adaptation planning?	**Score:** 0 **Comment:** No, since overshoot is absolutely a new concept for the policy makers here.	**Score:** 0 **Comment:** No consideration of any particular temperature thresholds or overshoot
Have you thought about impact ir/reversibility after overshoot?	**Score:** 0 **Comment:** No ir/reversible impacts assessed.	**Score:** 0 **Comment:** No ir/reversible impacts assessed.
Total Score:	**8**	**7**

The NAP and GBC currently hold a score of 8 and 7 respectively, out of a potential 28. This suggests a promising onset but also highlights the need for a deeper dive into the indicators outlined in the OPM, in order to refine and improve these policy documents. A more detailed and holistic approach is required that prioritizes cross-sectoral adaptation planning, focusing on the intricate interplay of climatic and non-climatic factors. Additionally, the long-term implications of the recommendations should be carefully evaluated, ensuring that the policies are robust and considerate of future developments and challenges.

4.5. Reflections on the co-development process

Stakeholder engagement for PROVIDE co-development process employed a multifaceted approach in UIB and Islamabad, utilizing workshops, webinars, in-person meetings, calls, and emails for concept dissemination, progress sharing, and gathering their input. While stakeholders demonstrated a limited familiarity with PROVIDE-specific concepts such as overshoot, unavoidability, and reversibility etc., their adept understanding of adaptation limits, particularly in socio-economic aspects, was notable.

Workshop/Webinar: Webinars and workshops emerged as the most dynamic forums, fostering heightened and most active stakeholder involvement. The stakeholders seemed to gauge PROVIDE deliverables better and responded effectively.

In-person meetings were effective for detailed discussions and locating data but lacked efficiency in obtaining collective responses from connected departments when quick answers regarding relevant authority/resource were needed.

Surveys: Online surveys had delayed responses if done via email, but they were promptly answered during workshops. Self-administered surveys proved less effective due to a lack of follow-up questions for detailed answers.

5. Bahamas and Nassau, The Bahamas

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5.1. Context and reference

The Bahamas is an archipelagic small island developing state (SIDS) comprising over 700 low-lying islands and cays with a total land area of approximately 14,000 km2 and a total sea area of approximately 260,000 km2. The country is mostly flat in elevation with the highest point being 63 meters above sea level. Approximately 29 islands of The Bahamas are permanently inhabited, with 70% of the total population of about 400,000 located on the island of New Providence which hosts the capital city of Nassau (Photo 8).

As one of the wealthier nations in the Caribbean region, The Bahamas' national economy is driven by tourism and financial services, both of which are vulnerable to processes of global environmental change and globalization. Like many SIDS, The Bahamas relies primarily on imports to satisfy basic goods needs, including fuel, food, and medicine.

The Bahamas is exposed to an array of climate hazards, making it one of the more vulnerable SIDS to the impacts of climate change. Tropical cyclones are a regular occurrence with a hurricane affecting at least one of the many islands of the country every two years on average. With more than 80% of the Bahamas' land surface area being less than 1 meter in elevation, sea level rise is a significant hazard with implications for storm surges, flooding, coastal erosion, groundwater salinization and loss of terrestrial territory. Ocean acidification and warming are also key hazards for The Bahamas, threatening the world's third longest barrier reef and 5% of the world's coral that are located within national borders. Extreme heat is a hazard of growing concern, as the national electricity provider has been unable to meet the current demand for cooling needs as ambient temperatures rise.

Photo 8: Nassau, The Bahamas © Parsons Photography NL (CC BY-SA 4.0)

There are a number of constraining factors that contribute to low adaptive capacity in The Bahamas. Limited land area constrains the feasibility of adaptation measures while economic and financial constraints make it difficult for both individuals and government actors to adapt. Policies and strategies focused on adaptation are dated, with the most comprehensive adaptation policy being the National Policy for Adaptation to Climate Change, developed in 2005 but with limited implementation to date. There are several ongoing projects that aim to update and expand adaptation planning, including sectoral adaptation plans for agriculture and health as well as a proposal to develop a National Adaptation Plan.

Despite the lack of an updated overarching adaptation policy or plan, there have been some ad hoc projects that have adaptation components. Non-governmental organizations are in the process of developing nature-based community adaptation plans. Infrastructural projects led by the Ministry of Works are in the process of being implemented in New Providence and in a few of the other less inhabited islands, largely focusing on manmade coastal protection such as groynes, sea walls, dykes and beach nourishment. The Ministry of Works is also developing an updated building code to replace the code last developed in 2003 and a land use plan that will take climate change impacts into account.

In terms of challenges to adaptation planning in The Bahamas, recent national documents highlight the varied constraints that have led to limited progress in adaptation. The Bahamas' Updated Nationally Determined Contribution (NDC) highlights that "many gaps remain in terms of scientific data and research/information needed to understand and assess climate change vulnerability across all sectors and legislation." The NDC also acknowledges that although adaptation policies and initiatives exist, many are "outdated and obsolete". Further constraints to adaptation are acknowledged in The Bahamas' First Biennial Report, which states that "Regarding Adaptation, stakeholders with technical capacity constraints, interorganisational coordination and communication within and between organisations, lack of adequate data, key equipment and regulatory frameworks, in addition to high capital costs were constraints and gaps observed in this reporting cycle."

The NDC identifies specific strategic components for adaptation that should be implemented by 2030 to reduce the country's vulnerability. These components focus on "strengthening national policies and planning across all sectors, leveraging funding for adaptation action, strengthen[ing] public health security and resiliency to climate-related hazards, enhancing management of natural resources and promoting nature-based solutions, and improving the resilience of all infrastructure while strengthening and mainstreaming climate change education and awareness across all sectors." The NDC lists examples of actions that can be implemented by 2030 to support the targets of the adaptation strategic components. Some of these actions are relevant for the current PROVIDE project: (i) conduct a study on economics of climate change in The Bahamas with a cost benefit analysis of adaptation actions, (ii) review and update the National Policy for Adaptation to Climate Change.

Overall, adaptation planning in The Bahamas is in nascent stages. While there are efforts being made within various agencies to consider climate change, there is a lack of trained personnel that are experienced and knowledgeable about the aspects of climate change that are relevant for each of the various sectors. Slow progress with implementation of the dated National Adaptation Policy as well as the lack of a national adaptation plan have resulted in a piecemeal approach to adaptation. The development of sectoral adaptation plans as well as a National Adaptation Plan are also progressing slowly and are largely led by external consultants due to the capacity constraints as it relates to adaptation planning. The lack of publicly available data or publicly available sectoral policies or strategies along with multiple projects being undertaken by different agencies with little coordination further inhibits holistic approaches to adaptation planning.

5.2. Modelling approach to overshoot and adaptation

5.2.1. Urban heat stress assessment using the UrbClim model: Nassau

Nassau experiences maximum temperatures above 20°C throughout the whole year and is characterised by a tropical monsoon climate. Despite being an island and experiencing a sea breeze, temperatures can also rise to high levels and combined with high humidities, lead to heat stress for inhabitants. This is for example reflected in the number of days with very high heat stress (Wet Bulb Globe Temperatures surpassing 29.5°C; Figure 36). Areas that are not shielded from direct sunlight, e.g., open spaces, such as the airport, experience highest heat stress levels. The high number of sealed surfaces limit the amount of evaporative cooling, adding to an increased heat stress experience. This is also the reason why the city on the eastern part of the island is popping up as a hot spot for heat stress. Generally, areas with high vegetation experience lowest heat stress levels, e.g., the areas in the western part of the island.

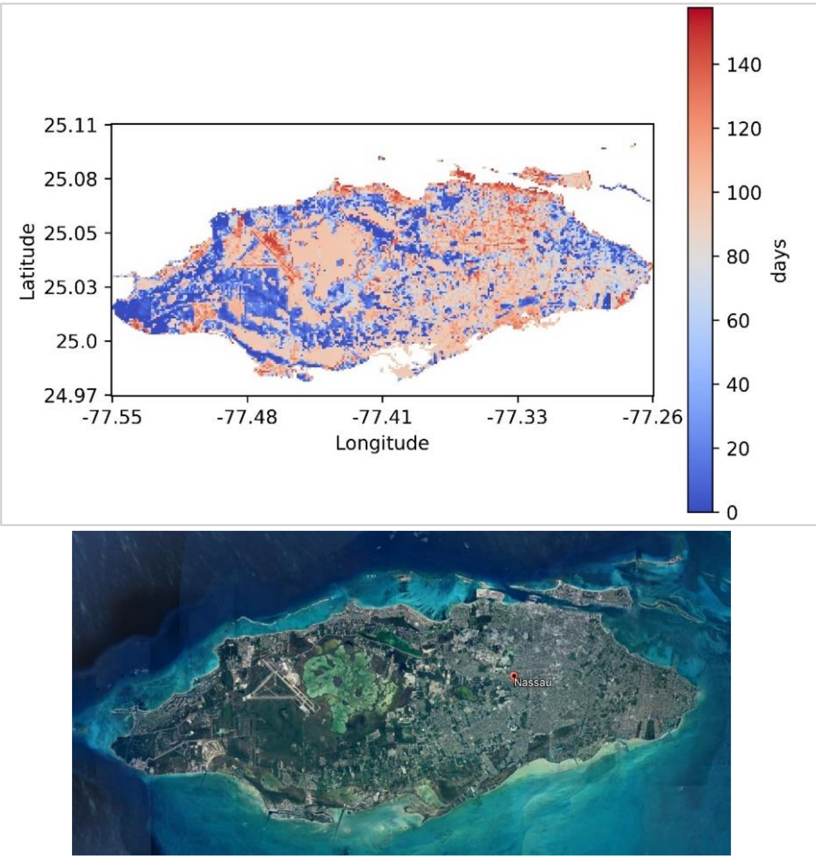

Figure 36: Number of days per year in which very high heat stress (Wet Bulb Globe Temperatures exceeding 29.5°C) is experienced (top). A satellite image of the island is provided as a reference (bottom).

Apart from heat stress during the day, people can also experience high temperatures during the night. This is particularly true over cities, where the Urban Heat Island effect, leading to higher temperatures in the city over night, is most pronounced. When visualising the number of heatwave days (days in which both the nighttime and daytime temperature is above the 90th percentile value; Figure 37), we see the city of Nassau pops up being a hot spot immediately. The high number of buildings and sealed surfaces absorb heat during the day, which is released during the night. Another remarkable observation is Lake Killarney, near the centre of the island, which pops up being a hot spot for heatwaves. This is caused by the high temperatures that are persistent during the night over the water, which cools down much slower than the land during the night.

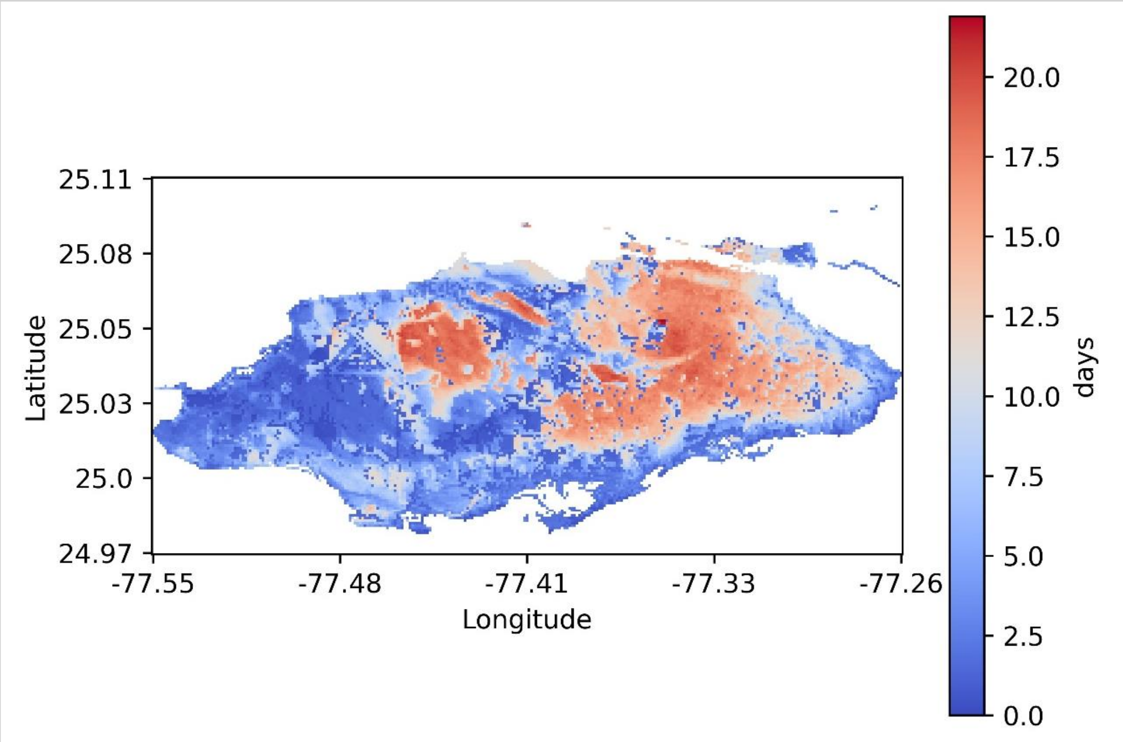

Figure 37: Number of heatwave days, defined as the number of days per year in which both daytime and nighttime temperatures are above the 90th percentile.

5.2.2. Urban Heat Impact Assessment using CLIMADA model: Nassau

Using the risk assessment model CLIMADA, the number of displaced people and the economic damages to physical assets from tropical cyclones was assessed for current climate and under the three PROVIDE climate overshoot pathways ("Current Policies", "Delayed action" and "1.5C – Shifting pathways"). Furthermore, the impact of past events between 1980-2020 was analysed and compared to the values reported by the International Displacement Monitoring Centre (IDMC) in their database (IDMC, 2022).

In order to derive the risk as defined by the IPCC, three contributors to risk, that is, hazard, exposure and vulnerability are required. In this study the hazards are tropical cyclone wind fields derived using the Holland et al. (2008) model from cyclone tracks at ~4km resolution. For the historical impact analysis, all tracks registered in the IBTrACS archive for the period 1980-2020 were used. Only those tracks that passed closer than 100km from any of the Bahamas's islands were considered. For the current climate risk, all tracks in the North Atlantic were extracted, and then a probabilistic statistical algorithm was applied to generate a probabilistic track set representative for the current climate conditions. These generated historical and probabilistic tropical cyclone sets are available from the CLIMADA data API. For the future climate, the probabilistic sets frequency and intensity distribution were modified based on the factors extracted from Knutson et al. (2020). To obtain these changes along the overshoot pathways, the factors were linearly interpolated from the RCP pathway-year with the closest temperature.

Two forms of the exposure were considered: (i) physical assets, and (ii) population distributions. The physical assets were modelled using LitPop, which combines population density and nightlight intensity to disaggregate the GDP in the year 2020 (Eberenz et al., 2020) at ~1km resolution. The population density was obtained from the Worldpop 2020 constrained dataset at 100m resolution (Bondarenko et al., 2020). Both the exposure and the hazard are obtained on a 500 m resolution.

A vulnerability curve for internally displaced people was calibrated on the data reported by the IDMC. Since the database contains entries for only 3 historical storms, one single function for all Caribbean countries was computed and used as a proxy for the Bahamas. For the physical assets, the calibrated curves from Eberenz et al. (2021) were used. Figure 38 shows the exposures and the vulnerability impact functions. Note that even though the hazard is represented by the wind only, the calibration does account for the impact of all sub-hazards (storm surge, pluvial flood and strong winds). In other words, wind is used as a proxy for all sub-hazards.

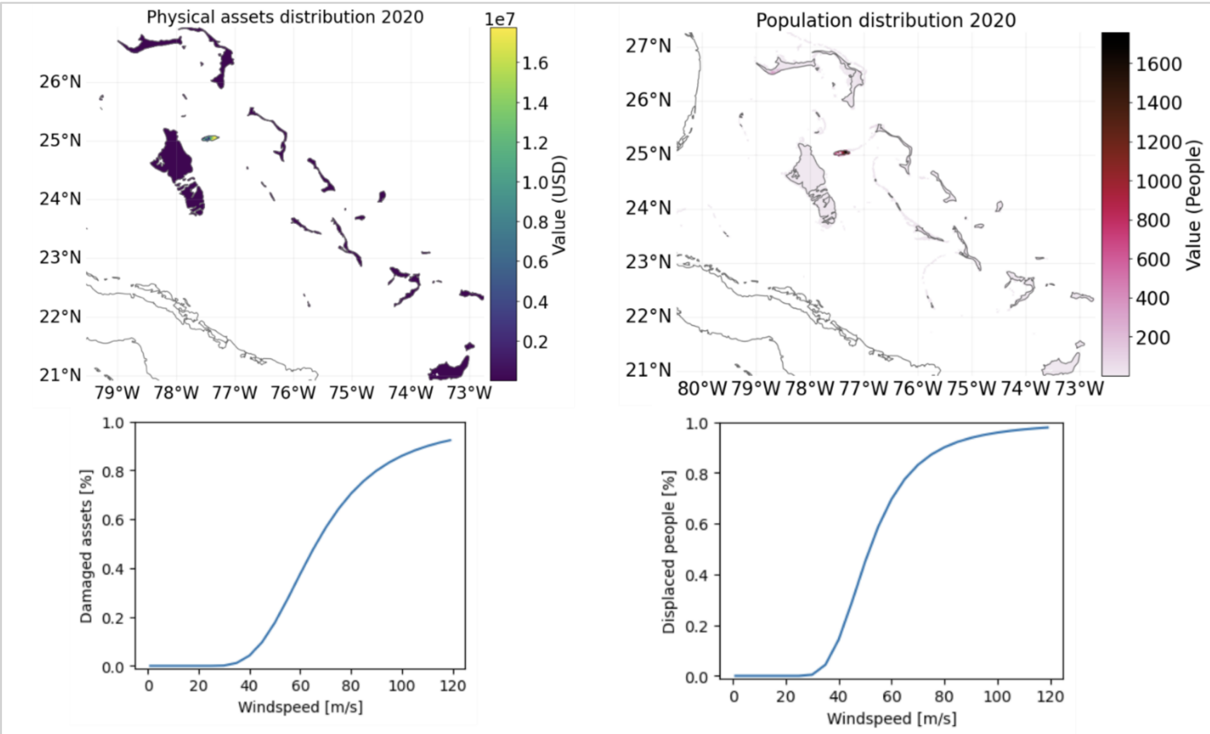

Figure 38: Asset distribution (left, top) and vulnerability impact function for asset damage (left, bottom). Population distribution (right, top) and vulnerability impact function for displacement (right, bottom)

Figure 39, below, shows return period curves for risk under current and future climates along overshoot pathways for mid-century (2040-2050) and end-of-century (2090-2100). The risk curves show little response in the "Delayed action" and "1.5C – Shifting pathways" scenarios even in 2090-2100 compared to current risk. For "Current policies" however, the impact of events with return periods above 20 years increases significantly by the end of the century. For instance, the 1/50 years assets damage increases by 15% and the displacement by 9%. Also, the impacts of the 1/50 years are expected 1/37 years for both asset damages and displacement. We remark that our model does not account for sea-level rise which likely would increase impacts of storm surges and coastal flooding in the Bahamas. We also do not consider any population growth or urban development. Thus, the change in risk comes exclusively from the climate change induced tropical cyclone distribution changes. Adaptation scenarios, including urban development might be explored in the next phase of the project.

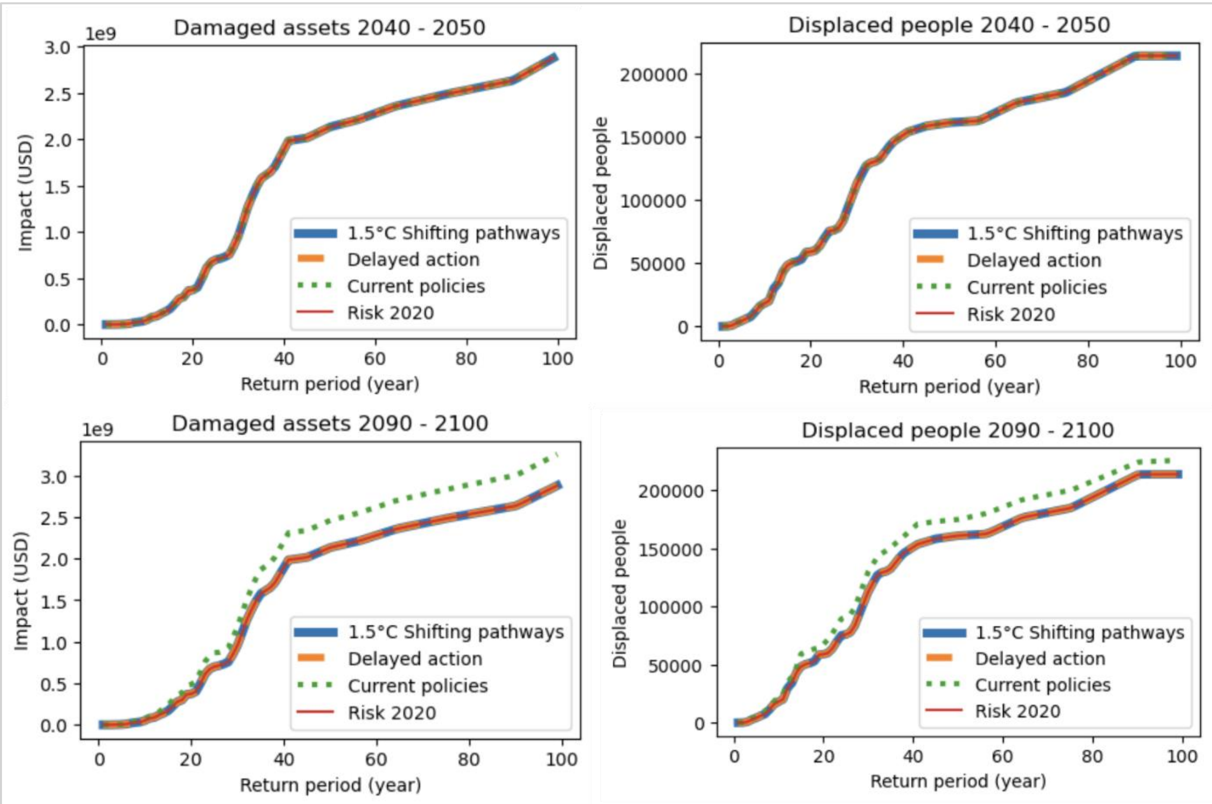

Figure 39: Return periods up to 100 years for damaged assets (left) and displacement (right), for mid-century (top) and end-of-century (lower) for the overshoot scenarios Current policies, Delayed action and 1.5C Shifting pathways. As reference the risk curves for 2020 are indicated in red

5.3. Spatial challenges and opportunities to overshoot adaptation

New Providence grapples with numerous environmental challenges given its low-lying topography, rendering it susceptible to sea-level rise, which leads to coastal erosion, increased flooding, and saltwater intrusion into freshwater sources. The island is also at risk from hurricanes and tropical storms, causing damage to infrastructure, service disruptions, and endangering public safety. The limited available land further complicates accommodating a growing population while preserving natural habitats and mitigating climate change impacts. Heavy reliance on groundwater exacerbates concerns of water scarcity due to over-extraction and saltwater intrusion. Additionally, climate change threatens the island's unique biodiversity, especially coral reefs and marine ecosystems, essential for local fisheries and tourism.

To effectively tackle these challenges and be prepared for overshoot scenarios, New Providence must leverage spatial adaptation opportunities. Extracted from the spatial strategic profile of the PROVIDE report on overshoot adaptation challenges for Bahamas, these opportunities include flexible land use planning that accommodates adaptive zoning. This means designating zones that can be reconfigured or repurposed when adaptation needs surpass standard expectations, such as creating buffer zones or green spaces capable of absorbing excess water. The analysis in the overshoot adaptation challenges report highlights significant room for improvement, particularly within Nassau's city centre. Expanding green infrastructure, like urban green spaces and rain gardens, not only provides essential ecosystem services but also enhances resilience, particularly in scenarios requiring adaptation beyond the norm. Updating and reinforcing building codes to withstand increasingly extreme climate conditions is equally crucial.

In coastal zones, in anticipation of rising sea levels and storm-related flooding, prioritizing elevated infrastructure designs that exceed minimum elevation requirements is key to bolster resilience and mitigate infrastructure damage and service disruptions.

In summary, New Providence can enhance its spatial adaptation opportunities by prioritizing resilience in infrastructure, land use planning, and environmental protection. Continual adaptation and flexibility are crucial for effectively addressing the evolving challenges of climate change in this vulnerable region. Ongoing research will focus on areas highlighted on the next page in Figure 40, characterized by increased impermeable surfaces requiring restructuring and connectivity. Additionally, a comprehensive approach to coastal protection, combined with micro-interventions for local water buffering and infiltration solutions, will be proposed at the scale of the island.

Figure 40: Green-blue system of Nassau centre image by BUUR/PoS 2022

5.4. Overshoot Proofing and stakeholder co-development process

The Overshoot Proofing Methodology (OPM) was applied to the National Policy for the Adaptation to Climate Change by the PROVIDE team.

Stakeholders for the PROVIDE project in The Bahamas were invited to a webinar to learn about the OPM and its relevance to local adaptation planning. Invitations were sent to all stakeholders that were invited to the first meeting in 2022 as well as to additional stakeholders that were identified through referrals. The webinar was held on 26 July 2023 and lasted for two hours. Key stakeholders responsible for national adaptation planning attended the webinar, including representatives from the Department of Environmental Protection and Planning and the Climate Change & Environmental Advisory Unit at the Office of the Prime Minister.

A presentation was given highlighting key concepts related to overshoot as well as the details of the OPM, followed by a discussion and question and answer session. During the discussion, participants indicated that current adaptation strategies and policies did not consider overshoot, nor link adaptation needs to different levels of global warming. However, consideration of overshoot was recognized as being highly relevant to adaptation planning and implementation in the Bahamian context by stakeholders.

The discussion also considered which adaptation planning policies or strategies would be most appropriate and beneficial to apply the OPM to. Stakeholders had a few suggestions. First was to consider the newly developed legislation on disaster risk management from the Ministry of Disaster Preparedness. Stakeholders were not aware as to whether or not the legislation included climate change adaptation or the time horizons for the legislation. If the legislation did not consider adaptation, the new building code was identified as another policy that could benefit from application of the OPM. The representative from the Department of Environmental Planning and Protection indicated that they are assessing the impacts of new buildings and developments on the coast in terms of how they would affect resilience to climate change and so the building code would be a good policy to assess.

Following the webinar, the Ministry of Disaster Preparedness and Ministry of Works were contacted to assess the feasibility of obtaining the recommended policies to apply the OPM. Given the timeline of the PROVIDE project and the unavailability of documents, application of the OPM to these documents was not feasible.

In a follow up correspondence with the Department of Environmental Protection and Planning, it was determined that applying the OPM to the National Adaptation Policy would also be helpful. Reviewing and updating the National Policy for Adaptation to Climate Change is identified as a priority in The Bahamas' Updated Nationally Determined Contribution and there are currently plans in place to begin this process. Providing feedback on the existing policy as it relates to overshoot proofing would provide beneficial inputs that would help with the reviewed and updated policy. Given the timeline of the PROVIDE project, applying the OPM to the National Policy for Adaptation was determined to be most appropriate for the Bahamian context.

5.4.1. Results

The results of the assessment provide a basis for further feedback and inputs by Bahamian stakeholders, as well as an example of how the OPM can be applied in the Bahamian context. The assessment of the National Policy for the Adaptation to Climate Change will be shared with stakeholders and will also be presented at the in-person meeting in Nassau in 2024. At the in-person meeting in Nassau, stakeholders will be invited to apply the OPM to other adaptation policies, plans or strategies.

The Bahamas National Policy for the Adaptation to Climate Change was developed by the National Climate Change Committee and The Bahamas Environment, Science and Technology Commission and was published in March 2005. The Preamble of the Policy begins with a strong footing in scientific evidence of climate change, stating that " The Government of the Commonwealth of The Bahamas accepts the findings of the Inter-Governmental Panel on Climate Change (IPCC), and of other expert scientific bodies, that global temperatures are increasing due to the release of so-called "greenhouse gases" (GHGs) into the atmosphere as a result of the burning of fossil fuels and other human activities. Government further accepts the scientific predictions that this trend of global warming is likely to continue for several decades, even if the causative activities were to cease immediately." Scientific evidence is further used to support statements on existing and projected impacts of climate change, and the vulnerability of The Bahamas as a small island state.

The policy provides an assessment of vulnerability to climate change by sectors, assesses the capacity for adaptation and provides strategies for adaptation, also by sectors. There is broad coverage of different sectors in the policy including agriculture, coastal and marine resources and fisheries, energy, financial and insurance sectors, forestry, human health, human settlement, terrestrial biodiversity, tourism, transportation, and water resources. These sectors cover the main contributors to GDP (tourism, financial and insurance sectors) as well as important ecosystems (coastal and marine resources and terrestrial biodiversity). The policy identifies the government as the major facilitator of the implementation of the policy directives and notes the need to improve the capacity and capability of The Bahamas to effectively adapt.

In what follow we present the five indicators, the seven questions, and the evaluated scores of each question.

Indicator 1: Global warming scenarios of 1.5°C, 2°C and 3°C

Question 1: Does the adaptation policy assess different global warming scenarios?

Score: 0 - the policy does not assess global warming scenarios

Comments: While the policy does acknowledge that global temperatures are increasing due to the release of greenhouse gasses, there is no mention of different global warming scenarios or specific levels of global warming.

The policy does state that "not all the processes relating to global climate change are fully understood, and that further research is required and is ongoing".

Indicator 2: Thresholds and limits

Question 2: Does the policy identify specific changes caused by climate change?

Score: 4: Many changes are assessed and clearly linked to climate change and adaptation options are developed based on these changes.

Comments: For each of the sectors included in the policy, impacts of climate change are provided. Impacts are discussed in largely qualitative terms. For example, for Agriculture, an impact highlighted is: "reduced production of some crops due to changes in rainfall seasonality, droughts, and agro-climatic regimes". While impacts are clearly linked to climate change, there is no analysis on the extent of potential impacts nor on impacts that may have already been experienced.

Following the qualitative assessment of climate change impacts for each sector, a series of policy directives are provided. However, many of these directives are broad and are left up to sectoral actors to develop in further detail. Again, for agriculture, a policy directive is: "adoption of appropriate adaptation measures to address areas of immediate need where this does not jeopardize or contradict the long-term sustainable strategies for the agricultural sector. Such measures may include soil conservation measures, and construction of water storage and irrigation facilities for crop production". For each of the sectors, development of a sectoral national adaptation strategy is provided as a policy directive, indicating a sector-specific approach to developing more detailed adaptation measures to respond to identified impacts.

Question 3: Does the policy identify thresholds and/or limits?

Score: 0: Thresholds/limits are not assessed.

Comments: No reference to thresholds or limits.

Indicator 3: Compound events

Question 4: Have multiple climatic and non-climatic risks which could particularly affect the systems related to the adaptation policy been considered?

Score: 2: Some compound events affecting the system are assessed.

Comments: There is limited reference to compound events for a few sectors. For biodiversity, non-climatic risks are acknowledged, including: "lack of appreciation, habitat destruction and fragmentation, overharvesting (especially of marine species), pollution, and invasion of alien species". Climate change is then identified as a threat multiplier by having impacts on biodiversity through catastrophic events that may cause habitat destruction and by direct modification of habitats.

However, for the majority of sectors, there is no acknowledgement of compound events and the policy directives for adaptation do not reflect consideration of compound events.

Indicator 4: Impact un/avoidability

Question 5: Are un/avoidable impacts identified in the policy?

Score: 1: Awareness of some long-term impacts but nothing about impact un/avoidability.

Comments: There is a passing reference made to long-term impacts in the Preamble: "Government further accepts the scientific predictions that this trend of global warming is likely to continue for several decades, even if the causative activities were to cease immediately". However, there is no inclusion on unavoidability of impacts in the remainder of the policy.

Indicator 5: Impact ir/reversibility

Question 6: Have you considered a potential overshoot scenario of 1.5°C global warming in your adaptation planning?

Score: 0: Overshoot is a new concept, and the policy does not plan for a global warming scenario beyond 1.5°C and its return to lower levels of warming.

Comments: There is no inclusion of particular temperature thresholds or overshoot.

Question 7: Have you thought about impact ir/reversibility after overshoot?

0: Impact ir/reversibility is a new concept, and the policy does not assess this.

Comments: There is no inclusion of overshoot and hence no inclusion of impact ir/reversibility

Overview of the total scores

The total score for the National Policy for the Adaptation to Climate Change is an 8 out of a possible 28, see summary in Table 5 below. According to the OPM, this score represents a good start, necessitating further familiarization with the indicators and further work on indicators with a score of less than 3.

Table 5: Overview of scores

Indicator	Question	Score
Global warming scenarios of 1.5°C, 2°C & 3°C	1. Does the adaptation policy assess different global warming scenarios?	0
Thresholds and limits	2. Does the policy identify specific changes caused by climate change? 3. Does the policy identify thresholds and/or limits?	4 1
Compound events	4. Have multiple climatic and non-climatic risks which could particularly affect the systems related to the adaptation policy been considered?	2
Impact un/avoidability	5. Are un/avoidable impacts identified in the policy?	1
Impact ir/reversibility	6. Have you considered a potential overshoot scenario of 1.5°C global warming in your adaptation planning? 7. Have you thought about impact ir/reversibility after overshoot?	0 0
	Total Score	**8**

5.5. Reflections on the stakeholder co-development process

For the review and updating of the National Policy for the Adaptation to Climate Change, key concepts to consider will be:

- Assessment of different global warming scenarios and linking adaptation needs to particular levels of global warming. Adaptation needs will be different at 1.5°C vs. 3°C for example.
- Identification of thresholds and limits. Thresholds and limits are particularly relevant for ecosystem-based adaptation measures and long-term responses to hurricanes and sea level rise.

- Consideration of multiple climatic and non-climatic risks. As global average temperatures increase, there are higher risks that climatic and non-climatic impacts will interact. There will also be a need for cross-sectoral adaptation approaches to ensure that adaptation in one sector is not mal-adaptive for another sector. This may have implications for the sectoral approach to adaptation planning recommended in the existing policy.
- Consideration of un/avoidable impacts. Some climate change impacts are already unavoidable regardless of how much mitigation is done in the future. This is particularly relevant for sea level rise and storm surge associated with tropical storms.
- Consideration of impact ir(reversibility). While some impacts may be reversible depending on the magnitude and length of overshoot, others will be irreversible. This is particularly relevant for coastal and marine resources such as coral reefs and mangroves which are often highlighted as potential ecosystem-based adaptation responses.

6. General discussion and conclusions

6.1. Implications for the PROVIDE Overshoot Proofing Methodology

The application of the Overshoot Proofing Methodology (OPM) in all four IC provides a first step towards resilient planning that accounts for overshoot scenarios in regions that present a high level of vulnerability to climatic changes. The application of the OPM to existing plans and policies during stakeholder workshops has reconfirmed a discernible gap in evaluating the potential ramifications of emerging climatic threats and their interplay with escalating vulnerabilities. It seems imperative to align policy formulation with scientific insights and further advance the discussion around discernible socio-ecological thresholds, irreversible impacts and adaptation limits.

6.1.1. Improvements to the Overshoot Proofing Methodology

After reflecting about its application, various improvements to the OPM can be put forward, in view of enhancing its applicability and efficacy. Some key common considerations and methodological shortcomings that arose from the application of OPM, include:

- There are still relevant knowledge-gaps for local stakeholders/practitioners that limit the understanding of the concepts of overshoot, avoidable/unavoidable impacts, reversibility of impacts and compound events. In addition, some questions in the OPM are generic and lack specificity and hence remain difficult to understand in terms of their application to the local context. Each of these questions, the concepts and assessment criteria need to be strengthened and perhaps complimented with a relevant regional example to improve understanding.
- The OPM pre-supposes the existence of adaptation strategies, but real-world limitations (e.g., technical, financial, and evaluative constraints) may impede the development and implementation of such strategies. Existing plans may lack alignment with future climate projections and early identification of thresholds and irreversible impacts may not be true for every region/country. In addition, adaptation strategies are context specific in each IC, including at its lower spatial scales of political/administrative organization, which makes it difficult to apply the OPM in practice.
- A tool for choosing adaptation strategies and impacts, priori the OPM application, would help stakeholders navigate the multiple options they might have available locally. In regional context, several plans exist that may be viewed as an adaptation strategy, from specialized national adaptation plans to more specific regional preparatory plans against expected hazards such as heatwaves. The absence of criteria within OPM for identifying plans and policies suitable for its application poses a challenge in identifying which policies/plans are most suitable for OPM application. For example, the OPM could include a list of multiple hazards to choose from, that impact a particular region (e.g., heatwaves, floods, landslides glacial lake outburst flood).
- Once the OPM is applied, the results do not inherently guide towards next steps. This is a particularly important shortcoming when the final score is low, which implies “poor” effectiveness of adaptation policies to overshooting scenarios and impacts. The analytical capacity of the OPM based on the results needs to be updated so that it can help stakeholders identify next steps.

Overall and since the main reason to do the OPM evaluation is to set a score of a policy, but perhaps more importantly, to raise the consciousness and emphasis on the concept of overshoot in adaptation planning, the scorecard is a good starting point for discussion but not for prompting a revision of the policy itself, which is a political and administrative process outside the scope of this project.

Finally, and since the scoring system may be viewed as criticism on regional efforts a shift from a score-based system to a more comprehensive and comprehensible evaluation system would potentially enhance the understanding and collaboration among stakeholders.

6.2. Feedback on the usefulness of the PROVIDE Climate Risk Dashboard

The PROVIDE Climate Risk Dashboard offers considerable advantages, particularly in regions where both the reliable climate projections and adaptation modules are currently lacking. The dashboard provides climate projections at high resolutions and a comprehensive overview of potential exacerbations or emerging challenges under overshoot scenarios by exploring sectoral impacts.

The presented data in the Climate Risk Dashboard not only facilitates the identification of escalating threats but also enables the formulation of proactive measures. Of particular interest to UIB stakeholders is the feature on adaptation options, as comprehensive planning across multiple sectors is often challenging to visualize, design, and implement. In our engagement with the stakeholders, we also found that many planners find the global data difficult to work with at the local level. As such, for example, many stakeholders in the Lisbon Metropolitan Area find particularly interesting the data on climate projections at high resolution (1 m) from the Climate Risk Dashboard.

Inclusion of multiple adaptation options under different scenarios is also considered useful for the practical application of the Climate Risk Dashboard. The stakeholders from IUB wished inclusion of local constraints, like financial and technical, and indigenous adaptation measures. The dashboard, therefore, is expected to not only serve a crucial role in supporting research but also contribute significantly to enhancing resilience in the face of climate-related challenges in each IR/IC. It is important to continue updating stakeholders on the Climate Risk Dashboard's next versions.

6.3. Implications for further work in PROVIDE with the regional stakeholders

Despite the varied audience participating and engaging in the PROVIDE workshops and webinars (e.g., regional and urban actors from government agencies, private sector entities, development partners, academia, research institutions, and adaptation practitioners) the concept of overshoot is not widely known among the participants. The workshops and webinars provided valuable insights that offer a clear understanding of the local context and point to ways the overshoot concept and impact ir/reversibility can be better understood and applied in adaptation practices.

The workshops and webinars conducted under the PROVIDE project have disseminated knowledge regarding potential overshoot scenarios and associated climatic threats. However, the immediate integration of overshoot scenarios into resilience planning is challenging. One of the main aspects hindering immediate integration is the lack of local expertise, data and the science-based approach that is central to OPM. Despite stakeholders contributing insights into the local context, impacts, vulnerabilities, and adaptation capacities, the incorporation of overshoot scenarios into adaptation planning requires a gradual approach.

Targeted information delivery through periodic engagements, without triggering stakeholder fatigue, can pave the way for overshoot proofing within the sectors. This strategic approach ensures that stakeholders stay informed and engaged over time, fostering a more receptive environment for the gradual integration of overshoot scenarios and proofing strategies into climate resilience planning efforts.

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8. Annexes

8.1. Indicators calculated by UrbClim

General Indicators

- **Average daily maximum temperature**: Average daily maximum temperature over the fully considered time frame.
- **Daytime Urban Heat Island**: Daytime Urban Heat Island, calculated as the average difference in daily maximum temperatures between each pixel and a rural pixel outside of the city. It captures the difference in temperatures due to human activities and the modification of land surfaces. A correction for topographic differences between pixels is considered by applying the lapse rate.
- **Average daily minimum temperature**: Average daily maximum temperature over the fully considered time frame.
- **Night-time Urban Heat Island**: Night-time Urban Heat Island, calculated as the average difference in daily minimum temperatures between each pixel and a rural pixel outside of the city. It captures the difference in temperatures due to human activities and the modification of land surfaces. A correction for topographic differences between pixels is considered by applying the lapse rate.
- **Average daily temperature:** Average daily maximum temperature over all time steps in the considered time frame.
- **Average daily maximum Wet Bulb Globe Temperature:** The Wet Bulb Globe Temperature (WBGT) provides an estimate of heat stress exposure for humans and is calculated following ISO 7243 norms. Heat stress limits are defined based on this publication and recommendations from the US Army. A detailed description of its calculation can be found in Lauwaet et al. (2020): doi:10.3390/cli8010006.

Energy Indicators

- **Annual average number of cooling degree hours**: Cooling degree hours is an international standard to estimate energy usage for cooling dwellings using air conditioning (American Society of Heating Refrigerating and Air Conditioning Engineers, 2021). It is calculated as the number of hours during which the temperatures rise over 25°C, multiplied by the number of degrees the temperature rises above 25°C. The yearly average value is shown.

Health Indicators

- **Number of heatwave days per year**: A heatwave is defined as a minimum of three days in which both the daytime and night-time temperature exceed the 90th percentile threshold of a base period (taken as the period 2011-2020). The indicator is depicted as the average number of heatwave days per year.
- **Heat-wave magnitude index daily (HWMId)**: The Heat-wave magnitude index daily (HWMId) is defined as the maximum magnitude of the heatwaves in a year. A detailed description can be found in Russo et al. (2015): doi:10.1088/1748-9326/10/12/124003.
- **Annual number of days Tmax > 25ºC:** Annual number of days in which the maximum temperature exceeds 25 °C.
- **Annual number of days Tmax > 30ºC:** Annual number of days in which the maximum temperature exceeds 30 °C.
- **Annual number of days Tmax > 35ºC:** Annual number of days in which the maximum temperature exceeds 35 °C.

- **Annual number of nights Tmin > 20ºC**: Annual number of nights in which the minimum temperature does not drop below 20 °C. This limit is considered a 'tropical night' by several European meteorological services.
- **Annual number of nights Tmin > 25ºC**: Annual number of nights in which the minimum temperature does not drop below 25 °C. This limit is considered a 'tropical night' by several South-European meteorological services.
- **Annual number of nights Tmin > 28ºC**: **Annual number of nights in which the minimum temperature does not drop below 28 °C.** This limit is considered a 'tropical night' by several South-East Asian meteorological services.
- **Annual number of days WBGT > 25ºC**: Annual number of days in which the Wet Bulb Globe Temperatures (WBGT) exceeds 25 °C. The WBGT provides an estimate of heat stress exposure for humans and is calculated following ISO 7243 norms. 25 °C is considered a limit for moderate average heat stress exposure and limits highest physical outdoor activities to avoid health risk exposure.
- **Annual number of days WBGT > 28ºC**: Annual number of days in which the Wet Bulb Globe Temperatures (WBGT) exceeds 28 °C. The WBGT provides an estimate of heat stress exposure for humans and is calculated following ISO 7243 norms. 28 °C is considered a limit for strong average heat stress exposure and limits physical outdoor activities to avoid health risk exposure.
- **Annual number of days WBGT > 29.5ºC**: Annual number of days in which the Wet Bulb Globe Temperatures (WBGT) exceeds 29.5 °C. The WBGT provides an estimate of heat stress exposure for humans and is calculated following ISO 7243 norms. 29.5 °C is considered a limit for very strong average heat stress exposure and limits most physical outdoor activities to a minimum to avoid health risk exposure.
- **Annual number of days WBGT > 31ºC**: Annual number of days in which the Wet Bulb Globe Temperatures (WBGT) exceeds 31 °C. The WBGT provides an estimate of heat stress exposure for humans and is calculated following ISO 7243 norms. 31 °C is considered a limit for extreme average heat stress exposure and limits all outdoor activities to a minimum to avoid health risk exposure.
- **Annual number of hours WBGT > 25 °C**: Annual number of hours in which the Wet Bulb Globe Temperatures (WBGT) exceeds 25 °C. The WBGT provides an estimate of heat stress exposure for humans and is calculated following ISO 7243 norms. 25 °C is considered a limit for moderate average heat stress exposure and limits highest physical outdoor activities to avoid health risk exposure.
- **Annual number of hours WBGT > 28 °C**: Annual number of hours in which the Wet Bulb Globe Temperatures (WBGT) exceeds 28 °C. The WBGT provides an estimate of heat stress exposure for humans and is calculated following ISO 7243 norms. 28 °C is considered a limit for strong average heat stress exposure and limits physical outdoor activities to avoid health risk exposure.
- **Annual number of hours WBGT > 29.5 °C**: Annual number of hours in which the Wet Bulb Globe Temperatures (WBGT) exceeds 29.5 °C. The WBGT provides an estimate of heat stress exposure for humans and is calculated following ISO 7243 norms. 29.5 °C is considered a limit for very strong average heat stress exposure and limits most physical outdoor activities to a minimum to avoid health risk exposure.
- **Annual number of hours WBGT > 31 °C**: Annual number of hours in which the Wet Bulb Globe Temperatures (WBGT) exceeds 31 °C. The WBGT provides an estimate of heat stress exposure for humans and is calculated following ISO 7243 norms. 31 °C is considered a limit for extreme average heat stress exposure and limits all outdoor activities to a minimum to avoid health risk exposure.
- **Annual number of nights WBGT > 25 °C**: Annual number of nights in which the Wet Bulb Globe Temperature (WBGT) does not drop below 25 °C. The WBGT provides an

estimate of heat stress exposure for humans and is calculated following ISO 7243 norms. 25 °C is considered a limit for moderate average heat stress exposure.

- **Annual number of nights WBGT > 28 °C**: Annual number of nights in which the Wet Bulb Globe Temperature (WBGT) does not drop below 28 °C. The WBGT provides an estimate of heat stress exposure for humans and is calculated following ISO 7243 norms. 28 °C is considered a limit for strong average heat stress exposure.

Economic Indicators

- **Annual lost working hours for intense activities**: The limits for safe working conditions under heat stress conditions are defined by ISO 7243 norms and Hooyberghs et al. (2017): doi:10.1007/s10584-017-2058-1. For intense activities (415W), the annual lost working hours is calculated as follows:

$$LWH = 1 - \begin{cases} 1; & WBGT < 26.55918 \\ -0.1656 * WBGT + 5.3982; & 26.55918 \leq WBGT \leq 32.59783 \\ 0 & WBGT > 32.59783; \end{cases}$$

- **Annual lost working hours for moderate activities**: The limits for safe working conditions under heat stress conditions are defined by ISO 7243 norms and Hooyberghs et al. (2017): doi:10.1007/s10584-017-2058-1. For moderate activities (300W), the annual lost working hours is calculated as follows:

$$LWH = 1 - \begin{cases} 1; & WBGT < 31.0 \\ -0.5 * WBGT + 16.5; & 31.0 \leq WBGT \leq 33.0 \\ 0 & WBGT > 33.0; \end{cases}$$

- **Annual lost working hours for light activities**: The limits for safe working conditions under heat stress conditions are defined by ISO 7243 norms and Hooyberghs et al. (2017): doi:10.1007/s10584-017-2058-1. For light activities (180W), the annual lost working hours is calculated as follows:

$$LWH = 1 - \begin{cases} 1; & WBGT < 31 \\ -0.5 * WBGT + 16.5; & 31 \leq WBGT \leq 33 \\ 0 & WBGT > 33; \end{cases}$$