Deliverable Report

Online climate change ‘hot-spots’ prioritisation module

Deliverable accompanying document & user guide

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Authors: Dionysios Nikolopoulos, Iosif Spartalis, Christodoulos Pantazis & Christos Makropoulos

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Contributors	Klio Monokroussou
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[1] PU = Public
CO = Confidential, only for members of the consortium (including the Commission Services)
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Abbreviations

Abbreviation / Acronyms	Description
DBMS	DataBase Management System
GCM	General Circulation Model
GUI	Graphical User Interface
FTP	Fille Transer Protocol
JSON	Javascript Object Notation
I&Ms	Indicators and Metrics
NetCDF	Network Common Data Form
NUTS	Nomenclature of Territorial Units for statistics
RCM	Regional
SSP	Shared Socioeconomic Pathways
TIFF	Tag Image File Format
WP	Work Package

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Executive Summary

This document describes the development activities undertaken or completed in period 01/09/2021 to 30/09/2022 of the IMPETUS project, including those carried out under WP3: *Exposure and Vulnerability Assessment*, task 3.3: *Identify and prioritise climate change 'hot-spots*', culminating in the deliverable D3.2: *Online climate change 'hot-spots' prioritisation module*. The key objective of the task is to create an online service, which acts as a tool that identifies regions with the highest exposure to climate risks, the highest vulnerability and/or the lowest adaptive capacity to climate change, so these should be prioritised for adaptation measures. Another major objective of the analysis is to consider climate projections and socio-economic variables into the assessment, at multiple regional scales, ranging from national to local. The service leverages datasets from various sources at different resolutions, curating them with aggregation pipelines. Within this deliverable, HIPS (Hot-Spot Identification and Prioritisation Service) is developed. The HIPS tool comprises:

a) A context broker, called Nessie, and a database to gather and store a multitude of vastly different datasets ranging from climate projections to socioeconomic drivers from various sources. Among the datasets currently in the database, there are global circulation models that produce climate projection (CMIP6), land cover data (CORINE), historical climate observations (ERA5) and statistical socioeconomic indicators from Eurostat. Nessie can communicate with application programming interfaces (APIs) to dataset repositories to make scheduled updates.
b) Tools and pipelines for curating datasets in a common regional format using the EU geographical Nomenclature of Territorial Units for Statistics (abbreviated NUTS). Dataset attributes can be aggregated in four levels: National level, NUTS level 1 (major socio-economic regions), NUTS level 2 (basic regions for the application of regional policies) and NUTS 3 (small regions for specific diagnoses). Also, finer spatial analysis scales can be supported by the tool in this hierarchical scheme for specific purposes, e.g., for analysis at IMPETUS demo site level.
c) Methodologies and routines for analysing user customizable hot-spots. The back-end engine of HIPS allows complex computations and spatial operations to combine datasets, e.g., normalization, rescaling, standardization, weighted sums, standard Euclidean distance, etc.
d) An interactive mapping service for visualisation and other libraries for graphics capabilities, such as charts of timeseries data and tables.
e) A graphical user interface (GUI) at the front-end of the tool, that acts as the central hub for user interaction in exploring the datasets and identifying regional climate change hot-spots.

With the developed HIPS tool, stakeholders can set up customised hot-spot analysis by combining different future climate projections with other indicators, leveraging the metric and indicator framework developed in IMPETUS task 3.2 and support decision-making and strategies about specific adaptation measures at a region. HIPS is vital for WP3 and will interact with many other tasks within IMPETUS, also at other WPs. As such, it will continue to be updated with more datasets and features as the project matures and further needs arise for identifying the vulnerable and least adaptive regions of EU against climate change. It is envisaged that HIPS will help support the European Commission's Green Deal and the Adaptation Strategy that aims to increase and accelerate the EU's efforts to protect nature, people, and livelihoods against the unavoidable impacts of climate change.

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1 Setting the scene

1.1 Climate change stresses and impacts

The climate is changing on a global scale, as the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC 2014) concluded that the warming since the mid-20th century has predominantly been due to greenhouse gas emissions from human activities, in particular the combustion of fossil fuels, agriculture and other changes in land use, and will continue to change for decades to come even with practices that could substantially reduce the greenhouse emissions. In the forthcoming years, climate change will likely impose significant alterations to all human and biological systems, inducing deviations to a multitude of environmental- significantly beyond what was considered typical- conditions (Piontek et al. 2014). Climate change projections stem from General Circulation Models (GCM), which are numerical models that simulate the climate system at a global scale in response to projections for changes in atmospheric concentrations of greenhouse gases and aerosol. The models simulate atmospheric processes at a horizontal resolution of between 50 km and 250 km and with 30 km to 80 km vertical layers, and the ocean processes at a horizontal resolution of between 20 km and 150 km and with up to 40 km vertical layers. The projected changes are likely to include (EEA 2017):

- Increased global warming between 0.3 and 4.8 °C for year 2100, depending on future greenhouse gas emissions. Already in Europe land areas surface temperature deviates 1.5 °C from the pre-industrialised era, more than the average global deviation, and projections show that it will continue to increase faster than global average temperature. Extreme heatwaves are projected to increase globally. In Europe in particular, the return period of such events may drop to two years under the most stressful emissions scenarios.
- Increased precipitation in high-latitude regions and the equatorial Pacific, whereas decreasing precipitation for many sub-tropical and mid-latitude regions, including the Mediterranean. In Europe, there is variability in the spatiotemporal distribution of changes. In northern Europe projections show annual increase in precipitation, with increases occurring mostly during winter. In contrast, annual precipitation decreases in southern Europe, especially during summer. However, extreme precipitation events are likely to occur more frequently all across Europe.
- Increased likelihood for other extreme events like hail.
- Changes in the cryosphere, in particular melting of large polar ice sheets in Antarctica and Greenland, shrinking of glaciers and Arctic Sea ice, and thawing of the permafrost, which could be drivers for further climate change through reinforcing feedback loops and also lead to sea-level rise and disruption to ecosystems and species.

These global climate deviations, if not addressed properly, are likely to induce impacts which may also continue to increase in severity in the coming decades. More specifically, in terms of ill health, adverse effects on ecosystems and damaged property and infrastructure and high associated costs. Examples of likely impacts include (EEA 2017):

- Increased water shortages is identified as one of the most important global risk factors (WEF 2014). The availability of drinking water is facing problems in terms of both quantity and adequate quality (Zimmerman 2008), due to the shifting hydroclimatic factors and a growing demand. Climate change is projected to aggravate reductions in total incident precipitation, and alter snowmelt patterns, leading to desertification and increased reliance on groundwater resources, which ultimately is likely to lead to saline intrusion due to low water table levels.
- Heightened pluvial flood risk with more high intensity rainfall events are projected (Trenberth 2007). Leading to increased chances of public health issues through drowning, heart attacks, injuries, infections, exposure to chemical hazards and mental health consequences arising from trauma, and also disruption of services, including health services, safe water, sanitation and transportation ways, and destruction of property.
- Heatwaves are projected to increase in duration, frequency and intensity leading to a substantial increase in mortality and morbidity over the next decades (WMO and WHO 2015) . Heatwaves are likely to affect particularly vulnerable population groups such as elderly people.
- Extreme cold spells, with projected shortened return periods, leading to severe physiological and pathological effects (Holmér et al. 2012) with increased mortality in vulnerable population groups, such as people with cardiovascular and respiratory diseases and the elderly, as a possible result.

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- Increase in vector-borne diseases, as climate can affect the life cycle and replication rate of viruses and other parasites, with already observed examples of expansion to higher latitudes of disease vectors such as the Asian tiger mosquito, the tick species Ixodes Ricinus, and the Phlebotomus sandfly, as a result of high temperatures anomalies. Also, water and food-borne diseases could be affected by climate change (e.g., increased risk of campylobacteriosis, cryptosporidiosis, vibriosis and salmonellosis.
- Reduced yield of crops in some regions, for instance in Southern Europe, due to heatwaves, droughts and floods, as well as changes in the duration of the thermal growing season in some other Northern European regions.
- Wildfires are more likely to occur due to droughts and heatwaves and have been shown to have severe health impacts (Analitis et al. 2012) and destruct ecosystems.
- Increased peaks in energy demand (and associated monetary costs) attributable to the projected increase in the use of heating- and air conditioning systems due to extreme temperatures.
- Hydroclimatic risk to hydropower production in some regions due to the shifts in seasonal water flows and also risks to other power plants that require water for cooling (e.g., nuclear and thermoelectrical plants).

Climate change urges strategic decision-makers globally and across all domains to mitigate and adapt, while weighing different interests and dealing with the long term uncertainty of climate projections. The Paris Climate Agreement (United Nations / Framework Convention on Climate Change 2015) has been a vital milestone as it sets out a global framework with efforts to limit global warming to 1.5°C by 2100 and keep it under the 2°C mark currently, to avoid the worse impacts of climate change. In 2021, as part of the Green Deal, the European Commission adopted a new Adaptation Strategy via a series of legislative proposals that aim to greatly reduce greenhouse emissions and protect nature and people from climate change impact. Among the first the action initiatives are:

- The European Climate Law for including the climate-neutrality by 2050 objective into climate-EU law.
- The European Climate Pact with the ambition to engage all societal pillars in climate action
- The Climate Target Plan for 2030 with the goal to reduce emissions by 55%.
- The New EU Strategy on Climate Adaptation to make Europe a climate-resilient society by 2050, fully adapted to climate change impacts. Its four principles are to make adaptation smarter, swifter and more systemic, and to accelerate international action on adaptation.

1.2 Climate change “hot-spots”

Because of the spatial distribution of deviations in the climatic variables in the projections, as well as the baseline climatic and environmental features of each world region, it is apparent that climate change will have a different impact at each region and that the climate deviations will be more pronounced in some- and less in other regions (Giorgi 2006). These regions which are either more responsive to climate changes or where climate change’s impact is larger, are termed “hot-spots”. The identification of climate change hot-spots is usually the basis of any analysis for prioritising mitigation measures and adaptation strategies (Piontek et al. 2014). Many methodologies have been proposed for identifying hot-spots, each focusing on specific aspects for assessment. Giorgi (2006) used the Regional Climate Change Index (RCCI) based on four relative (percentage ratio) variables, namely the change in regional mean surface air temperature relative to the global average temperature, and the changes compared to present day values of the mean regional precipitation , the regional surface air temperature interannual variability, and the regional precipitation interannual variability. Baeting et al. (2007) formulated the climate change index (CCI) that summarised by aggregation all climatic information into a single number, combining with weighted means indicators for change in annual temperature, change in the annual precipitation, occurrence of seasonal extreme events and change in extreme temperature events. Williams et al (Williams, Jackson, and Kutzbach 2007) used standardised Euclidean distance (SED) between variables in the multivariate climate space, based on GCM assessment to identify hot-spots with most response to change. Xu et al (Xu et al. 2019) developed the regional extreme climatic Change index (RECCI) as a sum of seven extreme events indicators from temperature, precipitation and wind variables, accounting for temporal and seasonal changes, without being sensitive to the GCM chosen. Turco et al (Turco et al. 2015) performed a SED assessment on the observed climate variables to identify contemporary hot-spots and to test the robustness and persistence of future projections.

However, along with the climate, the sociotechnical environment around us is rapidly changing across many domains, with unprecedented rate (Babovic et al. 2018; Nikolopoulos et al. 2019). The global

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population is growing but also ageing considerably in developed countries, with estimations of reaching 8.5 billion by 2030, with the urban population expected to absorb virtually all the growth (UNDESA 2019). In addition to population growth, large immigration waves significantly drive urban growth (Zimmerman 2008, UNDESA 2019). Driven by urbanization, population growth and other significant other socio-economic trends, the global population is strained by higher demand for water, food, energy and material resources. There is significant uncertainty concerning the future population growth, with expectations ranging from 6.9 to 12.6 billion by 2100 (KC and Lutz 2014), according to the Shared Socioeconomic Pathways (SSPs) by the climate change research community (Riahi et al. 2017). However, most of the growth is projected to occur in regions where the mean income is low or medium compared to the world average (Byers et al. 2018). Also, climate impact is not only depended on the severity of the deviations by climate change but also on the spatial distribution of the exposed population and their capacity to manage the climate risk. As such, the most vulnerable people that will face a higher level of climate change impact, are people that live in urban areas with significantly lower air quality and less green space, lack economic resources, suffer from poor health and other societal disadvantages, or those living in areas with undeveloped health infrastructure and border regions with endemicity of climate-affected diseases (Patz 2002).

Thus, taking into account the biophysical impacts of climate change and the apparent linkage between climate change vulnerability with societal characteristics (Fraser et al. 2013), vastly different hot-spots may arise by combining socioeconomic with climatic variables. Heyder et al. (2011) developed a generalised Γ-metric to quantify biochemical shifts and vegetation structural changes as an ecosystem impact indicator. This metric was also used by Piontek et al. (2014) alongside water availability, length of transmission period for malaria and indicative crop yields, as impact sectors for global impact models (GIM) combined with GCMs to identify hot-spots. Fraser et al. (2013) used seven socioeconomic variables to create an adaptive capacity model regrading cereal crop yield and combined it with GCM projections to identify vulnerable hot-spots of future climate-change induced droughts. Diffenbaugh et al. (2007) incorporated sea-level-rise vulnerability, poverty metrics and population exposure into the RCCI index, creating the national climate change index (NCCI). Byers et al. and economic growth (Dellink et al. 2017), combined them with three levels of(2018) used the SSPs as a framework for the societal changes and economic development, with projections for population (KC and Lutz 2014), urbanization (Jiang and O'Neill 2017) change in global mean temperature (1.5, 2.0 and 3.0 °C) and produced multi-sectoral (water, energy, food and environment) global hotspots, including 14 different types of hot-spot indicators and one aggregated indicator.

Methods for identification of climate change hot-spots and the subsequent prioritisation of the regions in direct need of adaptation measures, which take into account not only the climate variables, but also their complex intertwining with other socioeconomic changes, are pivotal for the European Union's Climate Adaptation Strategy. Climate change inevitably affects all Europeans, but the level of impact differs across groups and populations across society. Especially vulnerable are the social clusters in cities (Aalbers et al. 2014), although some rural areas due to poor access to services may be also heavily impacted by climate change (Kazmierczak 2015). Both EU and national climate policies should draw attention to vulnerable groups and implement equitable adaptation solutions with fair societal consensus and preserving productive sectors.

1.3 Aim and scope of this document

1.3.1 IMPETUS project

In 2021, as part of the Green Deal, the European Commission adopted a new Adaptation Strategy that aims to increase and accelerate the EU's efforts to protect nature, people and livelihoods against the unavoidable impacts of climate change. As climate change progresses irrevocably, urgent measures are needed for building resilience and adaptive capacity. Climate action is at the heart of the European Green Deal an ambitious package of measures ranging from ambitiously cutting greenhouse gas emissions, to investing in cutting-edge research and innovation, to preserving Europe's natural environment. As part of the emphasis in climate adaptation research efforts, IMPETUS is a European Union Horizon H2020 research and innovation programme, launched in October 2021, with the goal of accelerating Europe's climate adaptation strategy and meeting the European Union's ambitions to become the world's first climate-neutral continent by 2050. IMPETUS aims to turn climate commitments into tangible, urgent actions to protect communities and the planet by bringing together 32 partners from 9 countries. Seven diverse demonstration sites will be the pilot cases for the innovative solutions of the

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project, that represent seven of Europe's eleven biogeographical regions[1], i.e., Continental (Berlin-Brandenbourg region), Coastal (Catalan coast), Mediterranean (Attica region), Atlantic (Zeeland province), Arctic (Troms and Finnmark County), Boreal (Zemgale region) and Mountains (Valle dei Laghi area). Multidisciplinary teams will work with policy-makers, businesses and communities at local and regional levels and ensure that knowledge is created and shared together. Much of this activity will centred around 'Resilience Knowledge Boosters' (RKBs) based at each of the project's seven demonstration and testing sites. The RKBs provide a place for stakeholders to engage and create together; as a network, they will provide routes for knowledge flow and for successful climate adaptation approaches to reach other communities that need them. This approach will also improve risk assessment tools and models, facilitate better governance and economic decision-making, and achieve cost efficiencies in the successful solutions. In this way, IMPETUS will create pathways towards a climate-neutral and sustainable economy, while attaining fair and equitable solutions for all vulnerable parts of society. IMPETUS is divided to 8 work packages (WPs):

- WP1: Governance & Stakeholder Cocreation for Transformative Adaptation
- WP2: Digital and knowledge dimension of the Resilience Knowledge Boosters
- WP3: Exposure and Vulnerability Assessment
- WP4: Deployment of Solutions at demo sites
- WP5: IMPETUS Adaptation Pathways and Innovation Packages
- WP6: Boosting project impact
- WP7 Communication and dissemination
- WP8 Project management

1.3.2 Work Package 3: Exposure and Vulnerability Assessment

WP3 has a significant role in the IMPETUS project because its objective is to support strategic planning for the effective application of climate adaptation packages by developing and validating methodologies and tools for the assessment of European Regions and communities and their key system's exposure and vulnerabilities related to climate change related risks. To this end, within WP3 there are six Tasks. Their activities include:

- Develop and demonstrate novel holistic metrics and indicators, as well as evaluation methods and tools for the identification of European regions or communities that are the most vulnerable and/or of low adaptive capacity to climate change impacts and the evaluation of their exposure to risks. Also, evaluation of vulnerability and prioritisation of key systems whose urgent protection would significantly improve the region's resilience.
- Develop and operationalise resilience assessment methods and tools for vulnerable regions and their key systems, before and after the implementation of climate adaptation measures.
- Demonstrate integrative systemic risk analyses and management approaches, considering multi-hazards and cascading effects, as well as interdependencies between key systems to assess potential hidden risks or unintended effects, resulting from the innovation packages themselves, and identify parameters that need to be monitored (and their thresholds) as part of adaptation pathways.
- Develop and validate methodologies and tools to assess and improve the adaptive capacity and dynamic nature of adaptation pathways. Based on the parameters to be monitored and their thresholds provide the tools to build dynamic behaviour into the adaptation plans, including emerging problem inferences and contingency planning and support.

The six Tasks of WP3 are:

- Task 3.1: Generation of weather and climate data
- Task 3.2: Adopt and adapt indicators and metrics for climate change vulnerability, resilience assessment and pathway adaptation capacity
- Task 3.3: Identify and prioritise climate change 'hot-spots'
- Task 3.4: Analyse and assess resilience of key systems
- Task 3.5: Analyse and assess costs, benefits and risks related to interventions
- Task 3.6: Strategic Resilience and Multi-Hazard Management tool for identifying dynamic adaptation pathways

[1] https://www.eea.europa.eu/data-and-maps/figures/biogeographical-regions-in-europe-2

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1.3.3 Task 3.3: Identify and prioritise climate change 'hot-spots'

Task 3.3. is the activity that develops the climate change 'hot-spots' identification and prioritisation service (HIPS). It is a tool that leverages on the metrics and indicators (I&Ms) framework for climate vulnerability and adaptation that is being developed in task 3.2 (see IMPETUS Deliverable 3.1 for a full description or section 3.1 of this document for a shorter one). The I&Ms are utilised in assessment of resilience, vulnerability and exposure to risk of regions and communities. Climate change hotspots are identified, thus allowing decision-makers to prioritise adaptation measures to regions that have the most exposure to risk, are more vulnerable or lack adaptive capacity. HIPS can operate at various spatial scales, leveraging different resolutions of available datasets. The datasets used in the service consider socio-economic, physical and climatic variables from many different collections, giving the opportunity for hotspots to emerge under different climatic futures and different analysis needs (i.e., variables of interest). The methodology will take advantage of the analysis and decision process that has already taken place to identify the target regions of the project as well as insights from the stakeholders at the project (WP1) and demo-sites levels (WP4) to ensure that the resulting service is robust and firmly grounded in reality. Within IMPETUS, the service will be demonstrated to identify additional hot spots within the regions targeted through the cases and use this assessment as part of the discussion with stakeholders towards adaptation pathways (in WP5). Also, HIPS will be available as an online service through the RKBs digital dimension (WP2).

1.3.4 How to read this document

This document acts as an accompanying document to the IMPETUS deliverable D3.2, which is the online service HIPS, currently available as a testing environment at our team's host at https://impetus.uwmh.eu/, and at a later phase through the RKB's digital dimension (WP2). The service will be under active development throughout the project's lifespan, as it is linked with many other Tasks, both within WP3 and other WPs, and some functionalities and features will be added as the project progresses and specific needs arise. Also, the datasets that are needed for hot-spot identification and prioritisation will be constantly added, updated, and improved, meeting the finalised needs of the I&Ms framework of task 3.2, and also some visualisation and identification methods may change according to the tailored needs of the project's stakeholders cocreation activities (WP1) and demo-sites pilot applications (WP4). As such, this document provides:

- The description of the concepts and design choices of the service as well as the of the climate change hot-spot identification and prioritisation methodological framework in Section 2.
- An overview of the datasets currently in the service's database in Section 3.
- The technical description of the curation processes and analysis pipelines for each dataset collection in Section 4.
- The technical details of the service architecture in Section 5.
- The User guide describing the interactions with HIPS in Section 6.
- A detailed discussion about the links with other Tasks and WPs of the IMPETUS project, as well as a roadmap for future updates of the service in the next phases in Section 7.

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2 Design of the climate change hot-spot identification and prioritisation service

2.1 Implementing hot-spot analysis at a regional scale

Within task 3.2 an I&M framework is developed (see IMPETUS deliverable D3.1) that aims to be utilised as a flexible superset of climate-change related indicators, that cover different aspects of socioeconomic life. It is a medium sized, collection that can reflect regional vulnerability to climate change impacts and reflects on the efforts and changes towards climate change adaptation, acting as a monitoring framework for the prioritisation of regions and the manifestation of adaptation measures. The indicators and metrics required the collaboration of stakeholders and policy-makers so these were designed with unambiguity, easy understanding and the attribute of being quantifiable in mind. The superset generated comprised of indicators applicable at different spatial scales, i.e., some being attributable to national scale, some referring to local (e.g., city wide) scale. Thus, the indicators in terms of spatial coverage are divided in categories and subcategories to support different types of climate sensitive decision support. Moreover, the indicators divide into two supergroups vulnerability-related and adaptation-related. The indicators can be used in analysis of climate resilience (which is linked with task 3.4) and for analysis of hot-spot analysis of vulnerabilities, the goal of this deliverable. For each use case (e.g., a specific region, or IMPETUS demo site) stakeholders can determine a customised set relevant to their own contextual climate-related vulnerabilities and adaptation trajectories. Tables 1 and 2 demonstrate the categories and subcategories of indicators for the Indicators & Metrics (I&M) for the vulnerability and adaptation groups respectively.

Table 1: The Indicators & Metrics (I&M) vulnerability group.

Category	Subcategory
1 Health & wellbeing	1.1 Health Risk
	1.2 Health Infrastructure
	1.3 Socio-economic well-being
2 Food and finance	2.1 Food production
	2.2 Food finance
3 Water supply	3.1 Service delivery
	3.2 Water resources
4 Energy supply	4.1 Energy demand
	4.2 Energy provision
5 Innovation power	5.1 Economic
	5.2 Human Capacity
	5.3 Institutional Empowerment

Table 2: The I&Ms adaptation group

Category	Subcategory
1 Institutional strength	1.1 Coordination, strategies, plans & policies
	1.2 Laws and regulations
2 Allocated resources	2.1 Financing and incentive instruments
	2.2 Insurance and risk sharing instruments
3 Knowledge & education	3.1 Climate services and information tools

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	3.2 Awareness raising & capacity building
4 Adaptation interventions	4.1 Green measures
	4.2 Grey measures
	4.3 Behaviour change
	4.4 Non-specific

Within the methodological framework of task 3.3, the indicators from each subcategory will be used as the basis for the socioeconomic characteristics of each region, in order to capture vulnerability and adaptation capacity to climate change. Current regional values for these indicators are combined with future climate projections in order to identify hot-spots that need immediate attention in order to adapt to climate change. HIPS connects with its context broker, Nessie (see Section 5.1), to repositories of such datasets (such as Eurostat) and stores them in its database for further analysis. It should be noted that HIPS can handle projections of the I&Ms datasets as well, provided that these exist or are generated by users for a specific hot-spot assessment. In its current version HIPS includes many datasets conforming to the I&Ms framework (see Section 3.2 and 3.3) and will continue to be updated through the project's lifespan to meet data requirements for I&Ms and address specific needs that will arise from other Tasks and WPs (see Section 7).

In order to facilitate the hot-spot analysis, it is imperative to include climate projections under different futures. The context broker and the database that HIPS uses can connect with many providers for climatic data, but specifically at this version of the tool we use projections offered by CMIP6 collection (Eyring et al. 2016), which underpins the Intergovernmental Panel on Climate Change 6th Assessment Report. The GCMs the ensemble contains are coarse in spatial scale, but still much finer than the spatial scale at which the socioeconomic indicators are typically reported. The GCMs contain a multitude of climatic variables and other derivative datasets, accounting for the scenarios of the Shared Socioeconomic Pathways (SSP). Other regional (downscaled to Europe) climate models (with regional climate models - RCMs) will be incorporated in the next phases of the project, to support more detailed analysis for the demo sites at smaller scale, like the EURO-CORDEX ensemble for climate projections (Jacob et al. 2014).

For the spatial scale aggregation of climatic and socioeconomic datasets HIPS uses the standard European nomenclature of territorial units for statistics (NUTS) to define regions that conform well with an established hierarchical system to implement policy and decision-making. The idea behind NUTS is that statistical information at a subnational level is an important tool for highlighting specific regional and territorial aspects, instead of using national wide metrics. Eurostat data, which are a basis for many of the I&Ms datasets conform to this structure.

The NUTS classification (Figure 1) divides the economic territory of EU and UK into 3 levels:

- NUTS level 1, with 92 entities that correspond to major socio-economic regions.
- NUTS level 2, with 242 entities that correspond to basic regions for application of regional policies.
- NUTS level 3, with 1166 entities that correspond to small regions for specific diagnoses.

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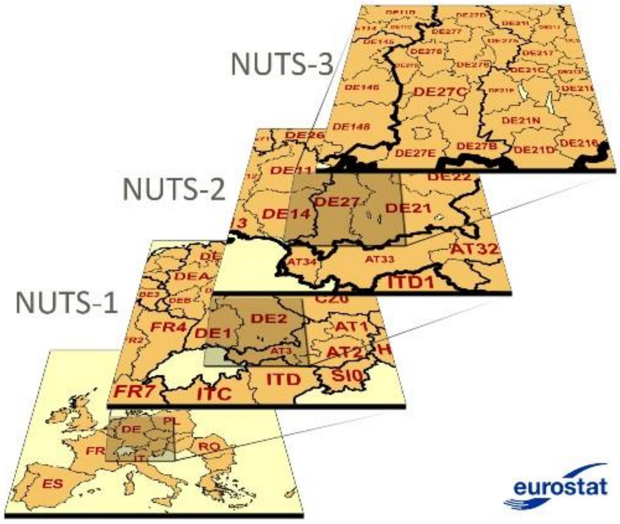

Figure 1: The NUTS hierarchical classification system[2].

NUTS level 3 is a fine scale for most applications of hot-spot identification and prioritisation, as it generally entails the smaller unit for administrative division of a state, thus being eligible as a target for adaptation measures against climate change. HIPS can also support finer spatial scales of analysis, if such need arises. Users can use shapefiles with more detailed sub-divisions for the NUTS 3 level region they are interested in (e.g., the demo sites of WP4), and the same data aggregation and curation pipelines (see Section 4) will apply. Figure 2 depicts the spatial coverage of NUTS level 3 in the environment of HIPS. All datasets in current HIPS version are either reported as values for NUTS or, for raster-type datasets, the spatial operation of union with overlapping NUTS entities is performed and statistical values are calculated. The average value for the variable in the dataset over a NUTS entity is used for reporting, although the database of HIPS also records other statistical properties (e.g., min, max, quartiles), as well as the original data. HIPS employs also a mapping service on the front-end, acting as the primary visualisation tool for the geospatial datasets (Figure 3). Custom colormaps can be defined for each type of variable.

[2] Image from https://ec.europa.eu/eurostat/web/nuts/background

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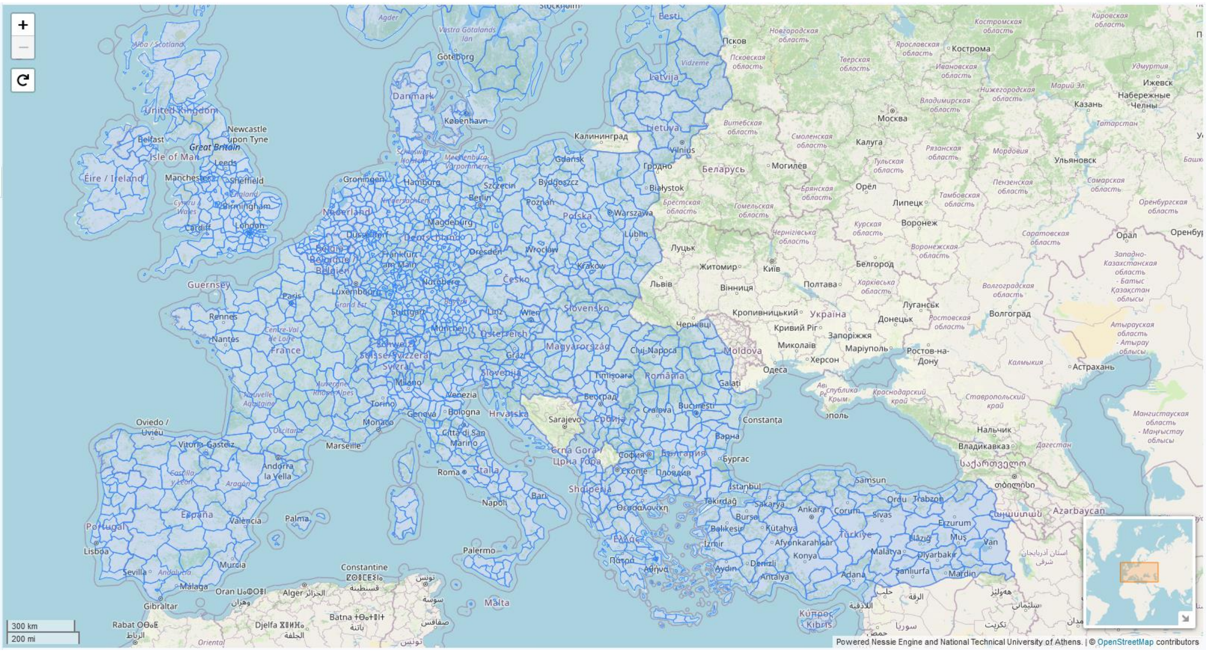

Figure 2: The NUTS level 3 coverage in the environment of HIPS.

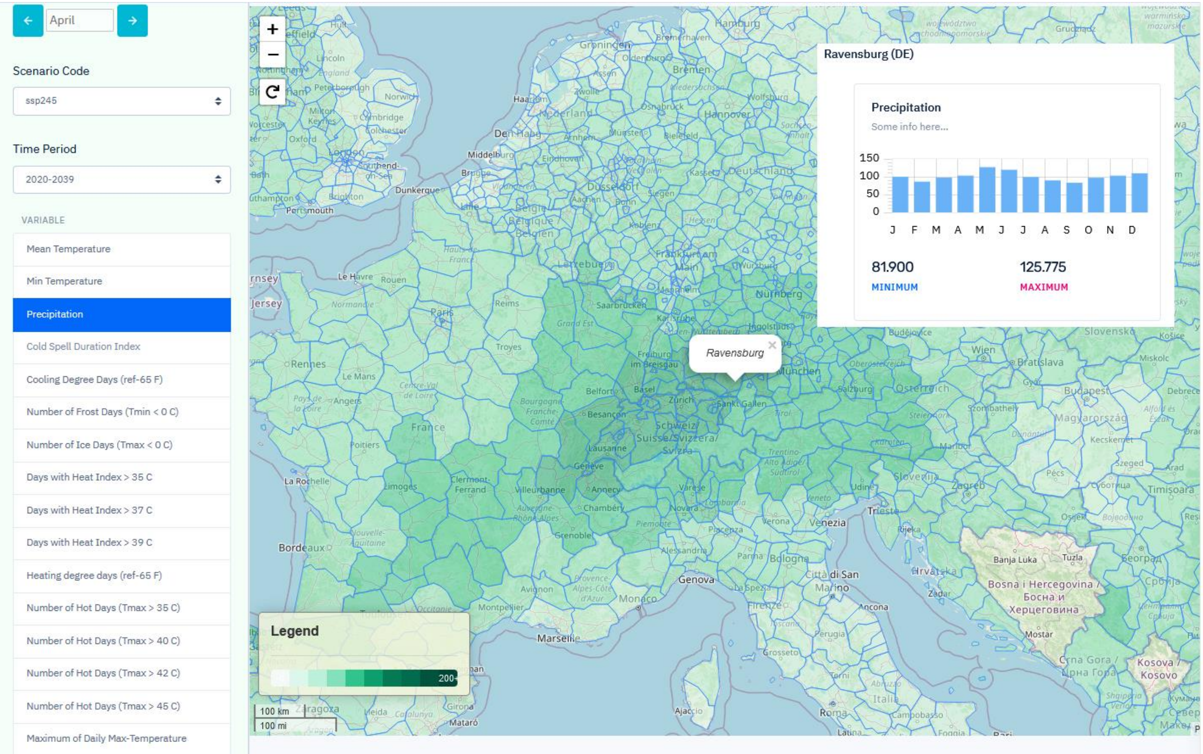

Figure 3: Custom colormap for climate projection CMIP6 dataset of April’s mean monthly precipitation for the time-period 2020-2040 over NUTS 3 level regions, as demonstrated in HIPS and specific data over a NUTS single entity.

The back-end engine of HIPS, Nessie, allows users to perform spatial queries to datasets of various collections to make a selection of socio-economic attributes and future climatic projections to create customised hot-spot analysis. Given that the level of spatial analysis may not be the same for every

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dataset, the hierarchical link of NUTS levels allows easy (in terms of computation) downscaling of datasets to finer levels using the values of the greater administrative level. As Figure 4 suggests, a user that selects a dataset with records only at NUTS level 2 and a dataset with records for NUTS level 3, can still perform a spatial operation that outputs a NUTS level 3 computation.

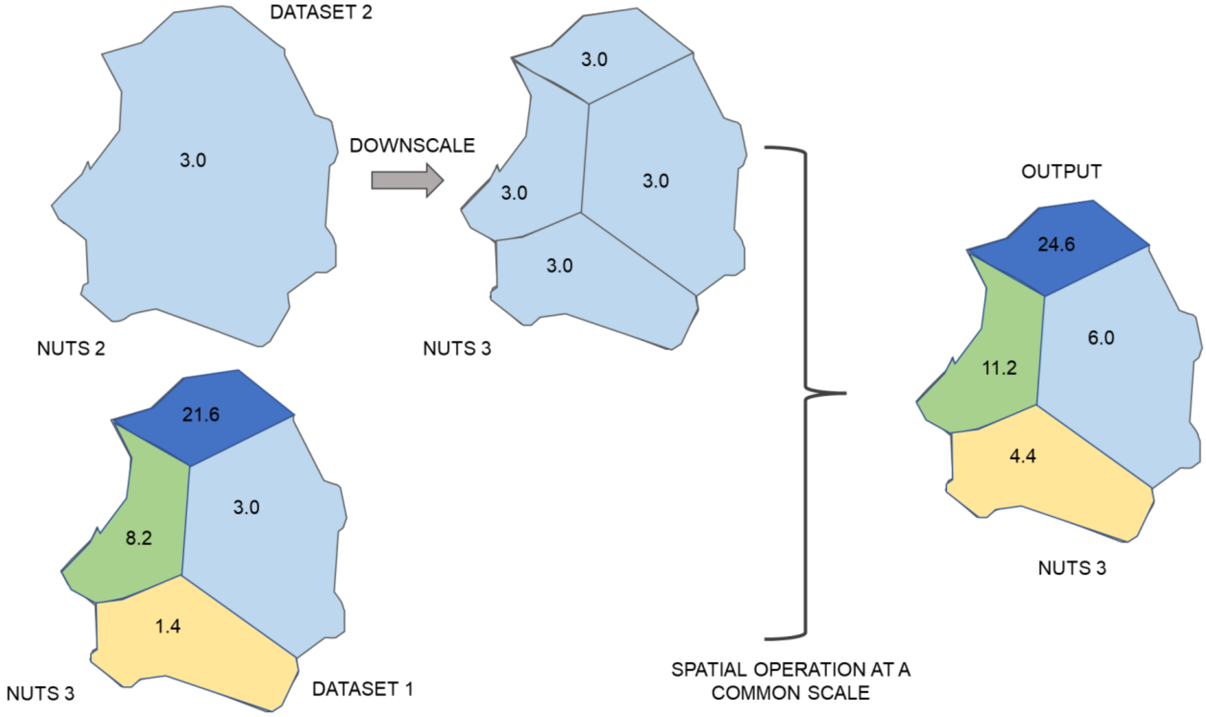

Figure 4: Handling of datasets of a different spatial scale.

Nessie allows many spatial operations and computations to be performed on the selected datasets. According to the user needs, datasets can be transformed and combined for hot-spot identification in the following ways, among other possible operations:

- Normalization of the dataset D, in the range of [0-1] relative to the range of values in the dataset, by calculating at each region i the normalised value:

$$\widehat{D_i} = \frac{D_i - D_{min}}{D_{max} - D_{min}}$$

- Standardization of the dataset at each region i (assuming a gaussian distribution of dataset values) relative to the mean value and standard deviation of the dataset:

$$\widehat{D_i} = \frac{D_i - mean(D)}{st.dev.(D)}$$

- Calculate percentage deviation of region i at period t $D_{i,t}$ from the reference (current/baseline) value $D_{i,0}$ of the dataset in case of future projections using:

$$\Delta D_i = \frac{D_{i,t} - D_{i,0}}{D_{i,0}}$$

- Perform standardised Euclidean distance standardization form the mean values of the datasets involved in a multivariate space relative to reference (current/baseline), using:

$$SED = \sqrt{\sum_{1}^{n} \frac{Dn_{i,t} - mean(Dn_{i,0})}{st.dev(Dn_{i,0})}}$$

- Set a threshold θ for a dataset to transform the value at region i to either a 0 or 1 (or other categories using multiple thresholds):

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$$\widehat{D_\iota} = \begin{Bmatrix} 1 \; if \; D_i > \theta \\ 0 \; otherwise \end{Bmatrix}$$

- Make weighted sums of datasets $D1, D2$ .., or their transformed versions $\widehat{D}1$, $\widehat{D}2$, ..., with weight values $w_1, w_2, \ldots$ denoting importance:

$$H = \sum w_1 \widehat{D}1 + w_2 \; \widehat{D}2 + \cdots$$

These spatial operations allow the user of HIPS to set up any customised hot-spot identification procedure, allowing for very detailed insights involving both the climatic projections and the human dimension in the identification and then prioritisation procedure. Hot-spots are mapped with HIPS mapping service, with a diverging colormap (can be customised by the user) and the user can visually identify which regions are more vulnerable or have less adaptive capacity to the selected narrative chosen/combination of parameters. The Graphical User Interface (GUI) at the front-end of HIPS will allow in the upcoming version the selection and operations via a wizard instead of scripting in the backend, with the goal to implement an interface tailored to the RKB's digital dimension (WP2) specifications and the stakeholders needs for user input at the activities of demo-sites (WP4).

2.2 Examples of hot-spots generated with HIPS

The following examples demonstrates the creation of custom hot-spots in Nessie by combining multiple datasets from the collections in the database (Section 3).

For the first example, a policy maker is interested in rural areas with intense agriculture activities that will be at flood risk by climate change, in order to prioritise adaptation actions to protect crops from flood damage. The user of HIPS selects from the database as indicators a dataset with projected precipitation extremes, a land cover dataset and digital elevation model (DEM), as presented in Table 3.

Table 3: Hot-spot dataset selection for the indicators of example 1.

Dataset	Collection	Parameters set	Regional threshold/sub-selection for the NUTS entity
Precipitation (single day extreme)	CMIP6 extremes	SSP: 5-8.5, Period: 2080-2100, Month: March, Return Period: 100 years	-
Land cover	CORINE 2018	-	Majority: agricultural land use
DEM	EU-DEM	-	DEM<100

Precipitation data are normalized, while the other two datasets are converted to a binary mask. All datasets are converted to a weighted sum with equal weights of 0.333, so the hot-spots that will emerge are enumerated in the range [0-1], with 1 showing areas where the most extreme values of single day precipitation are projected to occur, the majority of land use area is agriculture, and also these are European regions of low altitude, most in floodplains of large rivers. As seen in Figure 5, most hot-spots occur in the floodplains of Rhine, Elb, Scheldt, Loire, Thames, the Middle Lithuanian Lowland, the riparian lowland of Denmark, the Valley of Po and some regions around Danube.

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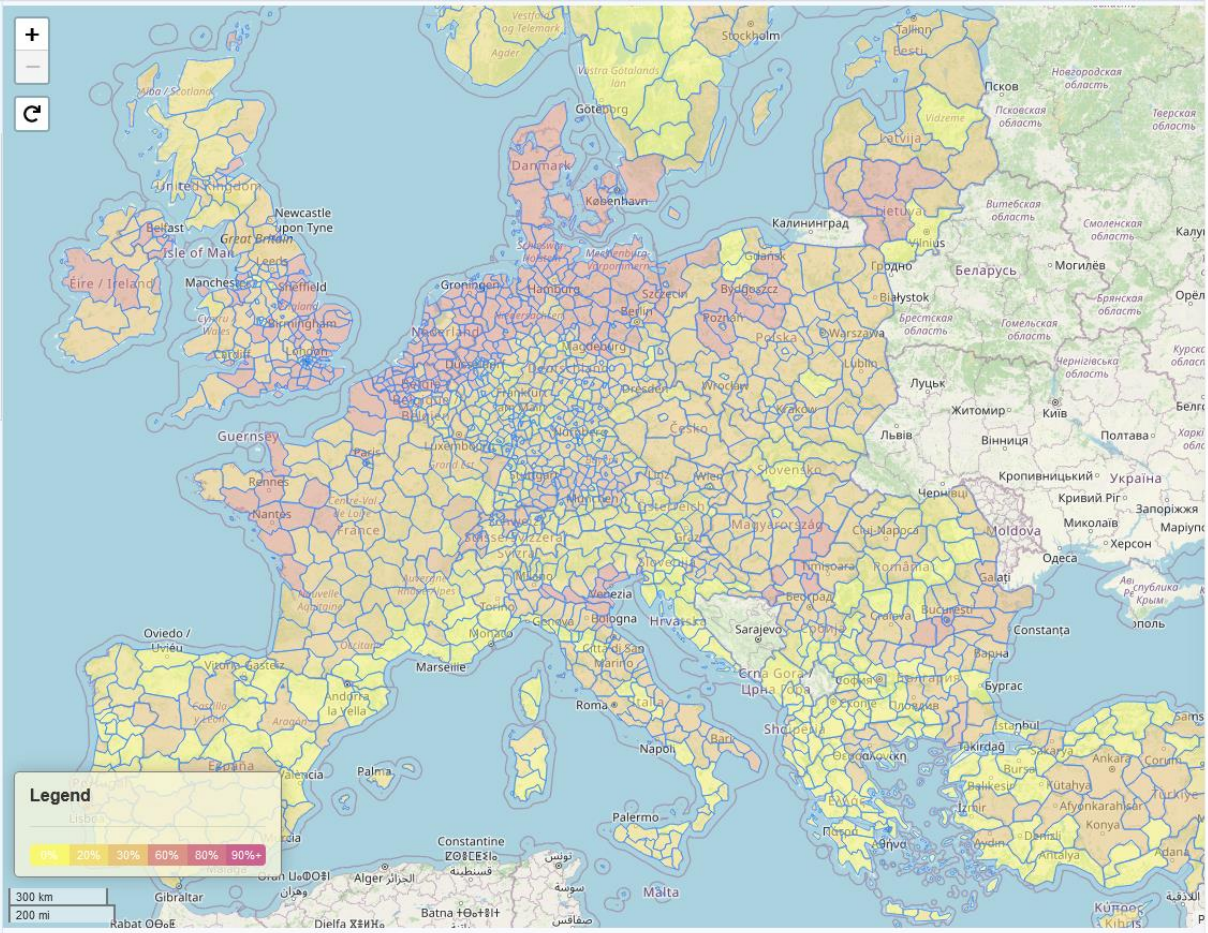

Figure 5: Hot-spots of rural areas in low elevation in flood risk by climate change.

For the second example, a policy maker wants to identify vulnerable urban regions for atmospheric pollution that will be impacted by climate change due to people resolving in impartially burning wood and other flammable sources as substitutes for more expensive heating commodities to combat cold winters for the period 2040-2060. The datasets selected as indicators for the analysis are the average monthly temperature, the percentage population at poverty risk dataset, the atmospheric pollution dataset with the assumption that already overburden regions will have less adaptive capacity, and a land cover dataset.

Table 4: Hot-spot dataset selection for the indicators for example 2.

Dataset	**Collection**	**Parameters set**	**Regional threshold/sub-selection for the NUTS entity**
Temperature (mean)	CMIP6	SSP: 5-8.5, Period: 2040-2060, Month: December	-
Land cover	CORINE 2018	-	Majority: artificial surfaces
Population at poverty risk	Eurostat	Percentage without confidence intervals	-
Air pollution	Eurostat	Particulates < 2.5 μm	-

Temperature, population at poverty risk data and air pollution are normalised (for temperature the scale is reversed with 1 denoting the lowest average temperature), while the land cover dataset is converted

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to a binary mask for urban areas. All datasets are combined with a weighted sum with weights of 0.5, 0.25, 0.15 and 0.1 respectively, so the hot-spots that will emerge are enumerated in the range [0-1], with 1 showing areas where the most vulnerable regions are projected to occur, if no adaptation measures are prioritised there. As seen in Figure 6 the hot-spots mostly emerge at regions of Romania and Bulgaria. Since the specific climate scenario selected here accounts for SSP5-8.5 (the highest emissions no-policy scenario), global mean temperatures rise significantly, with winter months being no exception. The comparison with other SSP based climate projections would be interesting, as winter temperatures would be actually lower. Note that some areas do not have records for all indicators selected, thus are not included in the analysis by default.

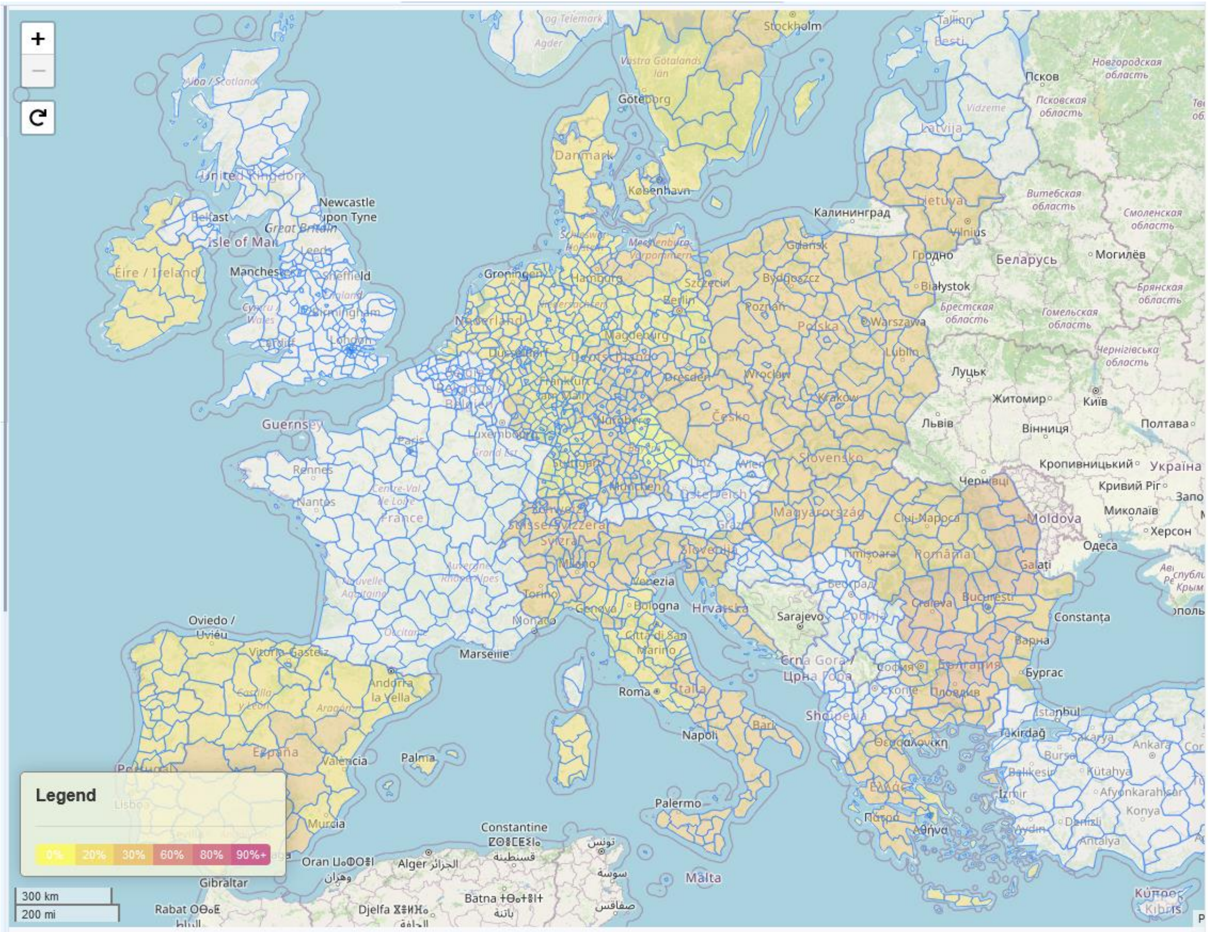

Figure 6: Hot-spots of urban areas in risk of winter air pollution due to burning of wood and other sources of particulates.

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3 Current data sources for climate impact hot-spots

3.1 Specific datasets currently in the database

Currently, there are 2009 datasets stored in HIPS's database. More specifically, there are:

- 609 datasets from *CMIP6* climate projections collection
- 378 from *CMIP6 Extremes* climate projections collection
- 24 datasets with historical climate data from *ERA5* collection
- 21 *Eurostat's* datasets
- *Corine Land Cover* dataset from *Copernicus* datahub
- *EU-DEM v1.1* Europe's digital elevation model from *Copernicus* datahub
- 972 from *IIASA's* hotspot explorer collection

Datasets CMIP6, CMIP6 Extremes and ERA5 are climate related datasets, with the first two collections to be future projections of climate related variables (Table 5) covering the time period 2020 – 2100, and ERA5 collection to contain historical climate data for the past period 1991-2020 (more information about the parameters of these datasets is presented in Table 6). Additionally, Eurostat's datasets include variables related with socioeconomic factors as can be seen in Table 7. Finally, IIASA's Hotspot datasets attempt to predict impacts, vulnerabilities and risks arising from development, climate change in the water, energy, and land sectors (Table 8).

Table 5: Climate related variables per dataset collection (CMIP6, CMIP6 Extremes and ERA5).

Variables	CMIP6	ERA5	CMIP6 Extremes
Mean-Temperature	**o**	**o**	
Min-Temperature	o	o	
Max-Temperature	o	o	
Precipitation	o	o	
Cooling Degree Days (ref-65*F)	o	o	
Number of Frost Days (Tmin < 0*C)	o	o	
Days with Heat Index > 35*C	o	o	
Days with Heat Index > 37*C	o		
Days with Heat Index > 39*C	o		
Heating degree days (ref-65*F)	o	o	
Number of Hot Days (Tmax > 35*C)	o	o	
Number of Hot Days (Tmax > 42*C)	o		
Number of Hot Days (Tmax > 45*C)	o		
Maximum of Daily Max-Temperature	o	o	
Minimum of Daily Min-Temperature	o	o	
Number of Hot Days (Tmax > 40*C)	o	o	
Number of Ice Days (Tmax < 0*C)	o	o	
Number of Summer Days (Tmax>25*C)	o	o	
Number of Tropical Nights (T-min > 20*C)	o		
Number of Tropical Nights (T-min > 26*C)	o	o	
Max Number of Consecutive Dry Days	o	o	
Max Number of Consecutive Wet Days	o	o	
Days with Precipitation >20mm	o	o	
Days with Precipitation >50mm	o	o	

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Average Largest 1-Day Precipitation	o	o	o
Average Largest 5-day Cumulative Rainfall	o	o	o
Largest Monthly Cumulative Precipitation			o
Precipitation Percent Change	o	o	
Precipitation amount during wettest days	o	o	
Relative humidity	o	o	

Table 6: Parameters of climate projections datasets CMIP6 and CMIP6 extremes and historical dataset ERA5.

	Socioeconomic Scenarios	Time periods	Type	Aggregation	Calculation	Percentage	model
CMIP6	SSP1-1.9, SSP1-2.6, SSP2-4.5, SSP3-7.0, SSP5-8.5	2020-2039, 2040-2059, 2060-2079, 2080-2099	Climatology	Monthly	mean	median	Multi-model-Ensemble
CMIP6 Extremes	SSP1-1.9, SSP1-2.6, SSP2-4.5, SSP3-7.0, SSP5-8.5	2010-2039, 2035-2064, 2060-2089, 2070-2099	Climatology	Return Future period 5-year 10-year 20-year 25-year 50-year 100-year	mean	median	Multi-model-Ensemble
ERA5	-	1991-2020	Climatology	Monthly	mean	-	-

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Table 7: Eurostat datasets and corresponding indicators from the I&M framework of task 3.2.

Dataset name	Dataset Eurostat code	Main category	Subcategory	Core indicator
Hospital beds by NUTS 2 regions	HLTH_RS_BDSRG	1. Health	1.2 Health Infrastructure	1.2.2 Patients capacity
Health personnel by NUTS 2 regions	HLTH_RS_PRSR	1. Health	1.2 Health Infrastructure	1.2.3 Workforce capacity
Persons at risk of poverty or social exclusion by NUTS regions - EU 2020 strategy	ILC_PEPS11	1. Health	1.3 Social well-being	1.3.1 Lack of social cohesion
Crimes recorded by the police by NUTS 3 regions	CRIM_GEN_REG	1. Health	1.3 Social well-being	1.3.2 Instability and violence
Urban population exposure to air pollution by particulate matter	T2020_RN210	2 Security of food & shelter	2.2 Climate-proof shelter	2.2.3 Particular air pollution
Population connected to public water supply	ENV_WAT_POP	3 Water supply	3.1 Service delivery	3.1.1 Percentage of households with improved water supply
Population connected to wastewater treatment plants	ENV_WW_CON	3 Water supply	-	-
Renewable freshwater resources	ENV_WAT_RES	3 Water supply	3.2 Water resources	-
Fresh water abstraction by source per capita - m³ per capita	TEN00003	3 Water supply	3.2 Water resources	-
Generation and discharge of wastewater in volume	ENV_WW_GENV	3 Water supply	-	
Available energy, energy supply and final energy consumption per capita	NRG_IND_ESC	4 Energy supply	4.1 Energy demand	4.1.1 Primary energy consumption per capita
Share of energy from renewable sources	NRG_IND_REN	4 Energy supply	4.1 Energy demand	4.1.1 Primary energy consumption per capita
Energy intensity	NRG_IND_EI	4 Energy supply	4.1 Energy demand	4.2.2 Primary energy intensity
Energy imports dependency	NRG_IND_ID	4 Energy supply	4.1 Energy demand	-

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Income of households by NUTS 2 regions, Inequality of income distribution	NAMA_10R_2HHINC	5 Innovation power	5.1 Economic	5.1.1 Income inequality
Central government debt	GOV_10DD_CGD	5 Innovation power	5.1 Economic	5.1.2 Public debt
Population by educational attainment level, sex and NUTS 2 regions (%)	EDAT_LFSE_04	5 Innovation power	5.2 Human capacity	5.2.1 Learning poverty
Seats held by women in national parliaments and governments	SDG_05_50	5 Innovation power	5.2 Human capacity	5.2.3 Lack of women's political power
Immigration	TPS00176	5 Innovation power	-	-
R&D personnel and researchers by sector of performance, sex and NUTS 2 regions	RD_P_PERSREG	5 Innovation power	-	-
Contribution to the international 100bn USD commitment on climate related expending (source: DG CLIMA, EIONET)	SDG_13_50	2 Allocated resources	-	-

Table 8: *IIASA hot-spot* datasets.

Sector	Socioeconomic pathway	Climate scenario	Threshold
• Land sector • Water sector • Energy sector • Multisector risk • Crop yield change • Agricultural water stress • Habitat degradation • Nitrogen leaching • Water stress	• SSP1 - sustainable scenario with continued progress on the sustainable development goals. • SSP2 - "middle of the road" scenario, with continued economic growth and development, and gradual improvements in inequality and sustainability. • SSP3 - unsustainable scenario with growing inequality.	• 1.5°C increase, referring to the aspirational targets of the Paris Agreement. • 2°C increase, referring to the aspirational targets of the Paris Agreement. • 3.0°C increase, approximately equivalent to global mean temperature under current mitigation policies.	• "Indicator score" - full range of scores. • "At risk" - locations above the moderate impact's threshold. • "Exposed" - locations at risk with population density above 100 people per km^2.

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• Groundwater stress • Drought intensity • Peak flows • Seasonality • Inter-annual variability • Clean cooking access • Heat stress • Cooling degree days • Hydroclimate risk to power plants			

3.2 Provision for other datasets

There can be three distinct cases for including new datasets to HIPS:

- A dataset source has an API: The context broker Nessie can utilize the API to gather new datasets and store then in the database. In case these datasets get regularly updated by the provider, Nessie can make scheduled (e.g., once a month) API calls to update the database.
- If no API is provided from the datasets source, administrators/developers should insert the datasets manually, create an endpoint in the back-end and set parameters for front-end integration.
- A user can set-up an FTP (File Transfer Protocol) server hosting uploaded datasets, and Nessie can connect to the server to download them.

New dataset collections will be included in HIPS throughout the project to support other Tasks and WPs, e.g., EUROPE-CORDEX regional climate projections, physio-geographical datasets about regions, environmental datasets.

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4 Data aggregation and curation pipelines

Due to the fact that as a base unit of this service is adopted the Eurostat's NUTS geocode standard for referencing, the subdivisions of countries for statistical purposes and the majority of the datasets mentioned in Section 3.3 (except Eurostat's datasets) have different base units and come in various file formats, data aggregation and curation pipelines had to be implemented. More specifically, climate and hotspot related datasets (*CMIP* family, *ERA5* and *IIASA Hotspots*) come in the NetCDF format, a convenient way of sharing spatial time series data, but current DBMSs do not support it, so an explicit pre-processing pipeline has to be implemented for transforming such data to a DBMS compatible structure. Furthermore, *Corine Land Cover* and *EU-DEM* datasets are in a TIFF format with a high spatial resolution and consequently have a very large size, making the data aggregation process resource intensive in terms of computer hardware, as a result a down sampling processing must be preceded before the aggregation procedure.

4.1 NetCDF Data curation-aggregation pipeline

Generally, a NetCDF file contains multiple slices of spatial data where the 3rd dimension usually represents time. In the cases of *CMIP6* and *ERA5,* each file contains 12 slices representing aggregated values of the specified variable for each month of the year. However, *CMIP6* Extreme files contain only one slice per dataset because they represent the aggregated value of the specified variable for the whole specified time period. By contrast, *IIASA Hotspot* files follow a different approach by storing multiple single slice datasets in a single NetCDF file, therefore all 972 datasets are stored in only 12 NetCDF files. Beside those differences, the main structure of the data processing pipeline remains the same and goes as follows (Figure 7):

1. Each dataset slice is extracted from each NetCDF file
2. Each extracted slice is spatial joined (intersect) with a Europe's NUTS shapefile
3. Aggregated values Min, Max, Mean and Median are calculated for each NUTS region (for all NUTS levels)
4. The aggregated values are stored in a JSON file
5. The produced JSON file is inserted into Postgres Database

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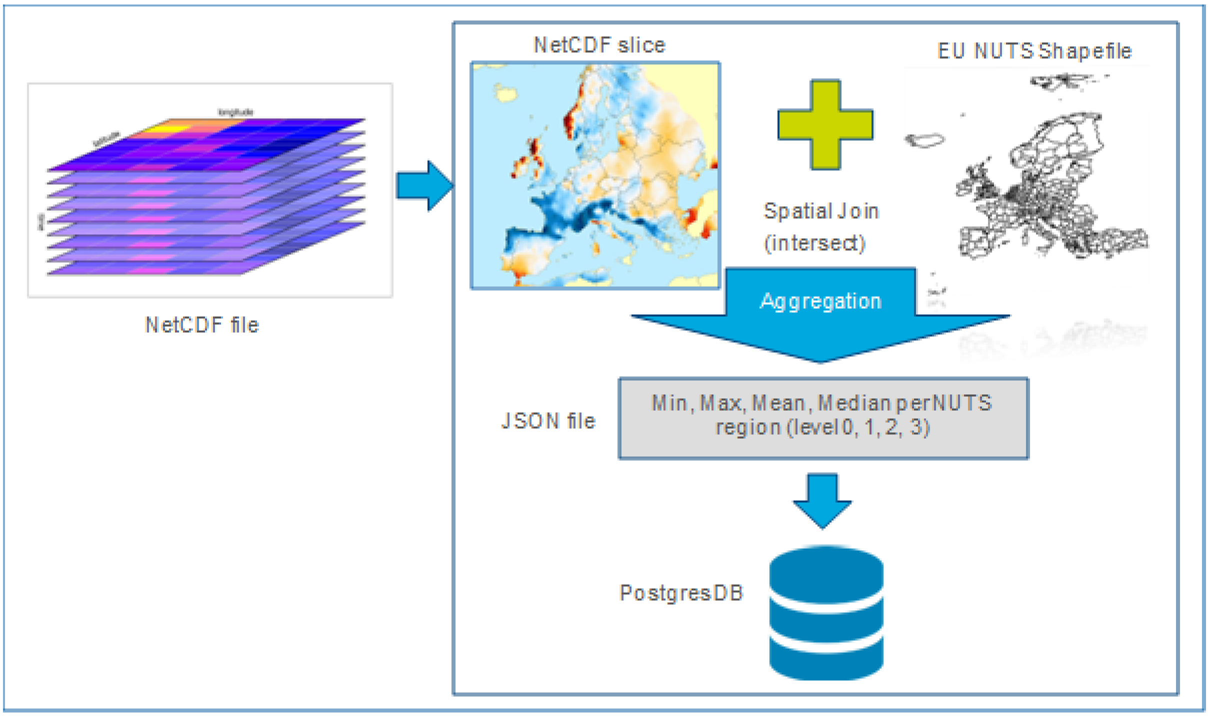

Figure 7: The NetCDF data curation-aggregation pipeline.

4.2 Corine Land Cover Data curation-aggregation pipeline

Corine Land Cover dataset comes in one single TIFF file of 200MBs depicting 44 land cover classes[3]. In general, this dataset has a 3-level hierarchical classification system with 5 main categories in level 0, while the 44 classes belong at the third and most detailed level. It was decided to keep only the 5 main categories in the final dataset (1. artificial surfaces, 2. agricultural areas, 3. forest and semi natural areas, 4. Wetlands, 5. water bodies), so a class merging procedure precedes the aggregation pipeline as shown in Figure 8. The resulting TIFF image is then spatial joined with the EU NUTS shapefile and eventually the majority class is found for each NUTS (level 3 only) region. The output of the aggregation is stored in a JSON file and finally is inserted into the database.

[3] https://land.copernicus.eu/eagle/files/eagle-related-projects/pt_clc-conversion-to-fao-lccs3_dec2010

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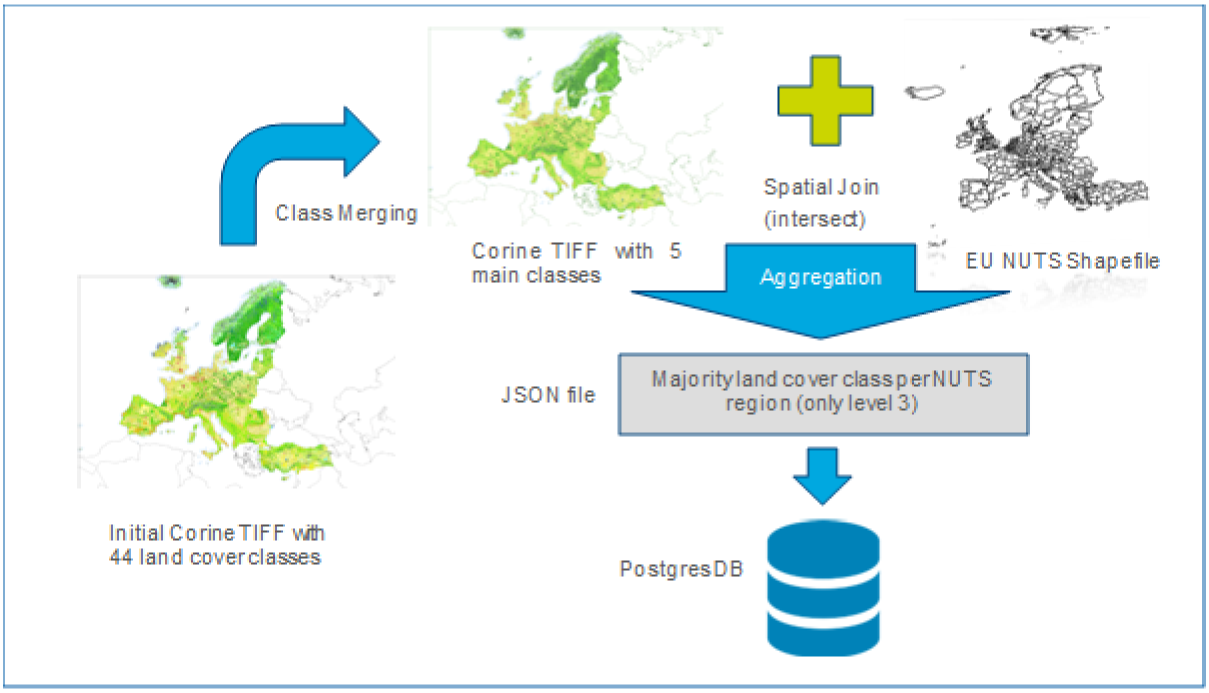

Figure 8: Corine Land Cover curation-aggregation pipeline.

4.3 EU-DEM Data curation pipeline-aggregation

EU-DEM dataset comes in 27 TIFF files with 25m horizontal resolution and with total size of 37GBs. Considering that the spatial join procedure with the NUTS shapefile requires a single TIFF file and merging the initial TIFF files will be impossible even in a high-end personal computer, a downscale procedure had to be implemented first, limiting the spatial resolution to 6.5km, a reasonable size considering that the final objective is to calculated aggregated height values for areas spanning tens of kilometres. Regarding the aggregation procedure, besides Min, Max and Mean, it is also calculated the elevation's standard deviation per NUTS region. It must be mentioned that the aggregated values are calculated for only NUTS level 3 regions, because aggregating elevation values for regions covering hundreds of kilometres does not provide representative information for the surface of those areas. Finally, the output of the aggregation is stored in a JSON file and finally is inserted into the database (Figure 9).

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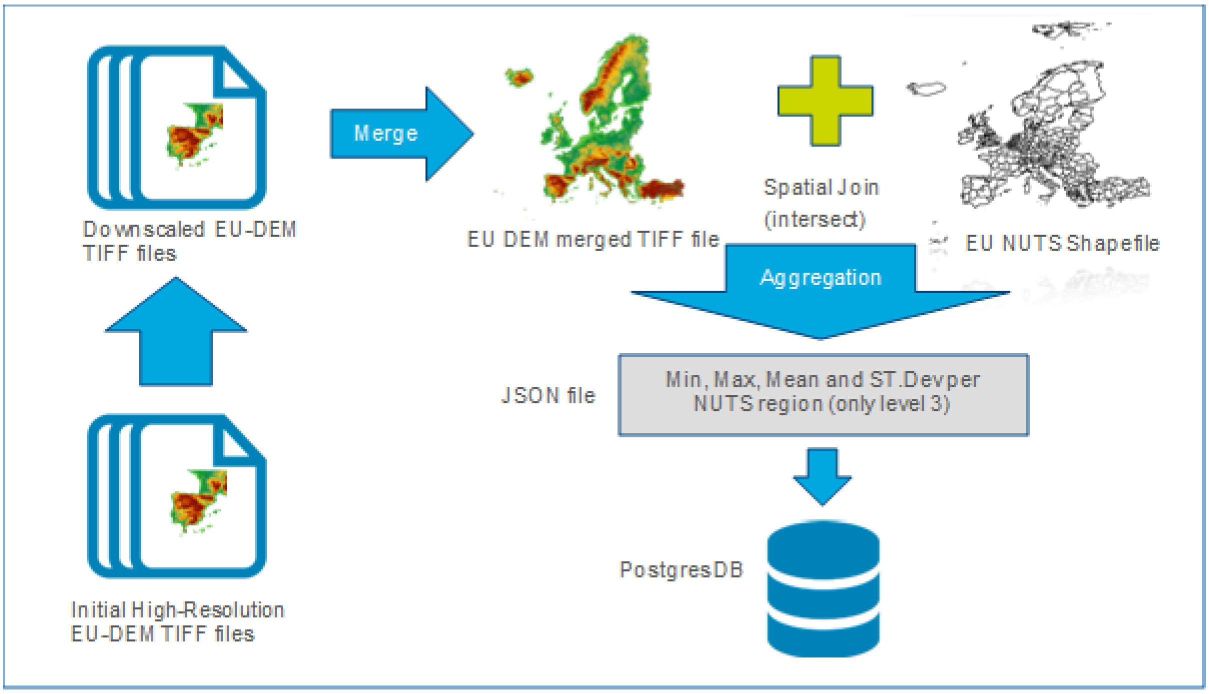

Figure 9: EU-DEM curation-aggregation pipeline.

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5 Technical details about the service's architecture

5.1 Back-end (server)

The Nessie engine lies at the centre of the project's architecture. Nessie is a back-end application, built by the National Technical University of Athens, which acquires, processes, stores, and manages high-resolution (temporal or static) data from any type of 3rd party client application which is able to perform simple HTTP requests. In order for Nessie Engine to accept data from 3rd party services or data repositories it provides a secure, fast and well-designed non-public API. Nessie can connect to public 3rd party data repositories using (a) their private of public API in order to download their data (in JSON or XML) or (b) using an FTP service to connect to a file server and download text files with temporal or static data.

Example clients can be web applications, sensors, smart meters, etc. Nessie engine can be coupled with an analytics engine to translate the data into information and provide visualisation capabilities and present the information to the end-users. An overview of the Nessie system is given in Figure 10.

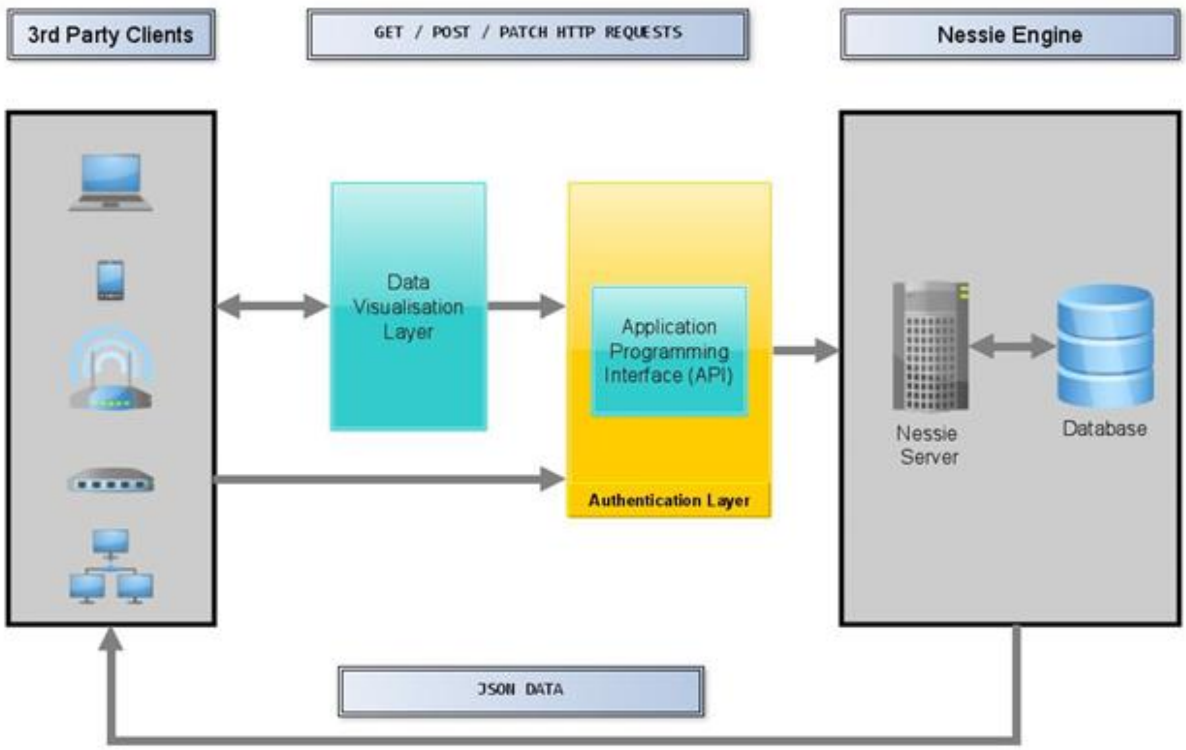

Figure 10: Nessie schematic diagram.

In practice, the Nessie Engine consists of a Web Server and a Geolocation-aware Database. The Web server provides a means (API) through which 3rd party clients can insert, update, and retrieve data. Data can be either temporal (e.g., a time-series) or non-temporal (e.g., a parameter set provided by an AI algorithm). The engine is responsible for receiving the data (included in the http request body), processing and storing them. It also provides a way to link data together (e.g., as in the case of an entity-relationship structure) and retrieve the data in a standard fashion using URNs.

The Data Visualisation Layer is provided by the Nessie Platform, but because of the latter's system-agnostic and independent nature of the design, any 3rd party stakeholder can create their own visualisation interface. When we refer to the Visualisation layer, we mean the graphs, charts, and all types of widgets that can be combined into a dashboard and provide useful information to the end user. Nessie Engine provides support for most of the common widgets (e.g., line charts, bar charts, pie charts, box plots, tables, gauges, etc.).

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The Web Server is responsible to authenticate the user, process the request and communicate with the database in order to store, update and retrieve data. All user http requests are served to the user by JSON objects, and all http requests must comply with the RESTful notation. Some of the Web Server's main components include:

- NginX Web Server (acts as a Reverse Proxy for static files)
- Gunicorn Python Web Server (receives and processes all of the http requests)
- Python/Django Framework
- Memcached Cache System
- REST Application Framework
- Data analysis Layer (Pandas/NumPy)

The database server is a PostgreSQL (version 12) running with GIS support, which allows for geographical queries to be executed. PostgreSQL is a fast, reliable, and one of the most robust database management systems than other open source (and free) database alternatives. It can be optimised quite easily and is replication-ready out of the box. Another advantage of PostgreSQL is the fact that it is licensed under BSD, which provides great flexibility in the utilisation of the service. The data exchange between Nessie and third-party systems is conducted on the basis of RESTful Requests and JSON files. Authentication is recommended but it is not required for public data (i.e., data that are retrieved by public repositories such as Eurostat).

5.2 Front-end (client)

The front-end (I.e. the Graphical User Interface) of the project is based on the concept of a single-page web application. Since the user interface is a single page application, all interactions are seamless, fast enough (depending on the load of data) and feature rich.

The main components are:

- Javascript
- jQuery / AJAX
- Bootstrap framework
- Leaflet Map Library
- OpenStreetMaps
- Flot Charts library
- Charts.js library

All the above tools, libraries and frameworks are open-source, free to use and easy to maintain since the community that supports them is active and growing:

- **jQuery** is a fast, small, and feature-rich JavaScript library. It makes things like HTML document traversal and manipulation, event handling, animation, and Ajax much simpler with an easy-to-use API that works across a multitude of browsers. With a combination of versatility and extensibility, jQuery has changed the way that millions of people write JavaScript. **AJAX** stands for Asynchronous JavaScript and XML. AJAX is a new technique for creating better, faster, and more interactive web applications with the help of XML, HTML, CSS, and Java Script. It lets us reload specific components of the web page instead of the whole page (since the HTTP protocol is a stateless protocol) and this makes the interaction between the user and the application seamless and less frustrating since the waiting times are lower and the interface is more responsive.

- **Bootstrap** is a free, open-source front-end development framework for the creation of websites and web apps. Designed to enable responsive development of mobile-first websites, Bootstrap provides a collection of syntax for template designs in order to help developers build web application which respond to any screen size.

- **Leaflet** is an open-source JavaScript library used to create interactive web maps. It is lightweight, relatively simple, and flexible. For these reasons, Leaflet is probably the most popular open-source web-mapping library at the moment. As the Leaflet home page puts it, the guiding principle behind this library is simplicity, although advanced functionality is still available through the use of special plugins. Leaflet uses **OpenStreetMap** Data. The OpenStreetMap

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(OSM) project, inspired by Wikipedia, was launched in 2004 to implement the idea of crowdsourcing in the field of spatial data and mapping. The aim of OSM is to create and maintain a single up-to-date digital map database of the world, through the work of volunteers, as an alternative to proprietary, out-of-date, and fragmented data, predominantly used in the past. The OSM project is a big success: in many places, such as the U.S. and Western Europe, the level of detail and quality in OpenStreetMap is as good as commercial and government data sources. The most important difference between Google Maps and OSM is that if someone contributes to OSM, data belong to the contributor and OSM community, and stay free and open for everybody, under creative commons license. Therefore, we decided to use OpenStreeMaps to load the base layer map and the map tiles. In order to display charts and other graph data, we decided to use the **Flot** and **Chart.js** libraries. Both libraries are AJAX friendly (that is, they fully support real-time updates through asynchronous data calls), have profesionally crafted visual components and supprot fast loading times.

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6 User guide

This section gives an overview of user interactions with HIPS (in its current version). Upon visiting the website hosting HIPS, the user interacts with a landing page with information about the IMPETUS project and the tool. By closing the landing page, the workspace environment of HIPS appears (Figure 11).

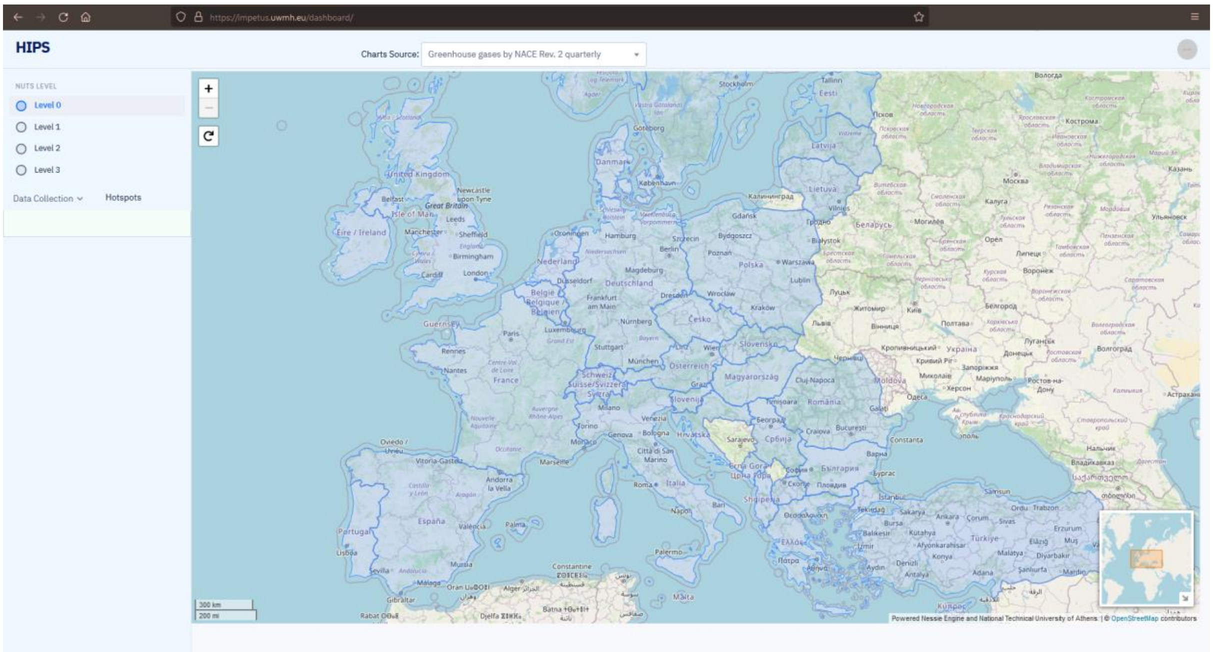

Figure 11: The workspace of the Hot-Spot Identification and Prioritisation Service (HIPS).

The centre space holds the *mapping service module*, which is responsible for visualisations of datasets and hot-spots. The *map service module* holds a window with a basemap layer from OpenStreetMap[4] project, which is draggable by clicking and holding, and has a "+" button for zooming in, a "-" button for zooming out, and a "reset" button for recentering the map around Europe at default zoom level. On the left of the mapping is the *main user interaction module* (Figure 12) which holds an assortment of options and hidden panels. From the top, the use can find four *radio buttons* that alter the *regional level* of analysis and visualisation for data, from National level to NUTS level 1,2 and 3.

[4] Map data copyrighted OpenStreetMap contributors and available from https://www.openstreetmap.org

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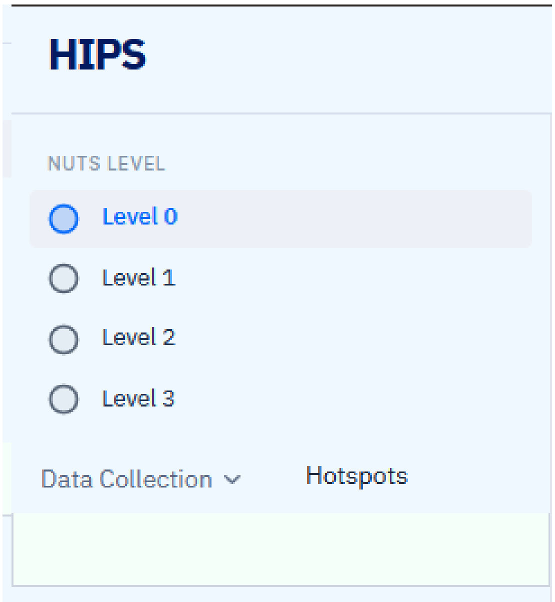

Figure 12: The main user interaction panel.

Underneath the regional level of analysis options there are two tabs, each fetching a different user interaction panel into the GUI. By clicking on the *Data Collection* button, a dropdown list emerges, which lists the currently available data collections in the Nessie database.

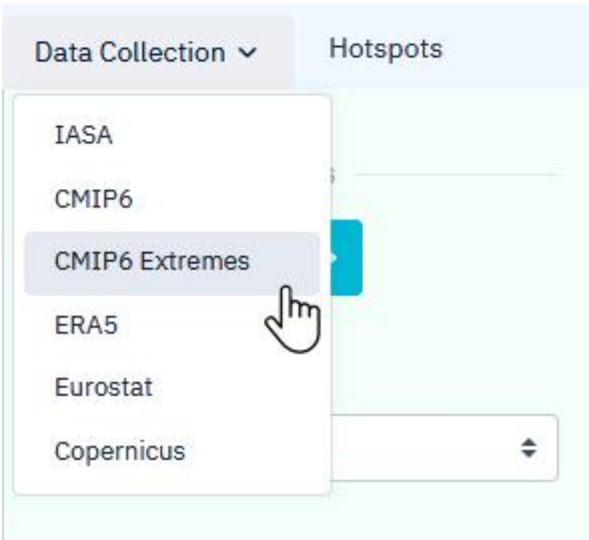

Figure 13: Using the Data Collection tab.

After clicking on a specific collection, a hidden panel appears that prompts the user for selecting a specific dataset from the collection and choose parameters for analysis (if applicable). Each collection brings a much different panel, according to attributes found in the datasets, and can be customised in the backend of HIPS. For example, by selecting the CMIP6 collection as presented in Figure 14, it is possible to select a dataset, e.g., *Mean Temperature*, and set attributes of the collection, e.g., *Month, SSP scenario*, and *time period*. By setting all attributes, the front-end of HIPS sends a request to Nessie's database and loads the requested dataset at the specified regional resolution, e.g., NUTS level 3, at the window of the *mapping service module*, with the specified colormap options set at the back-end.

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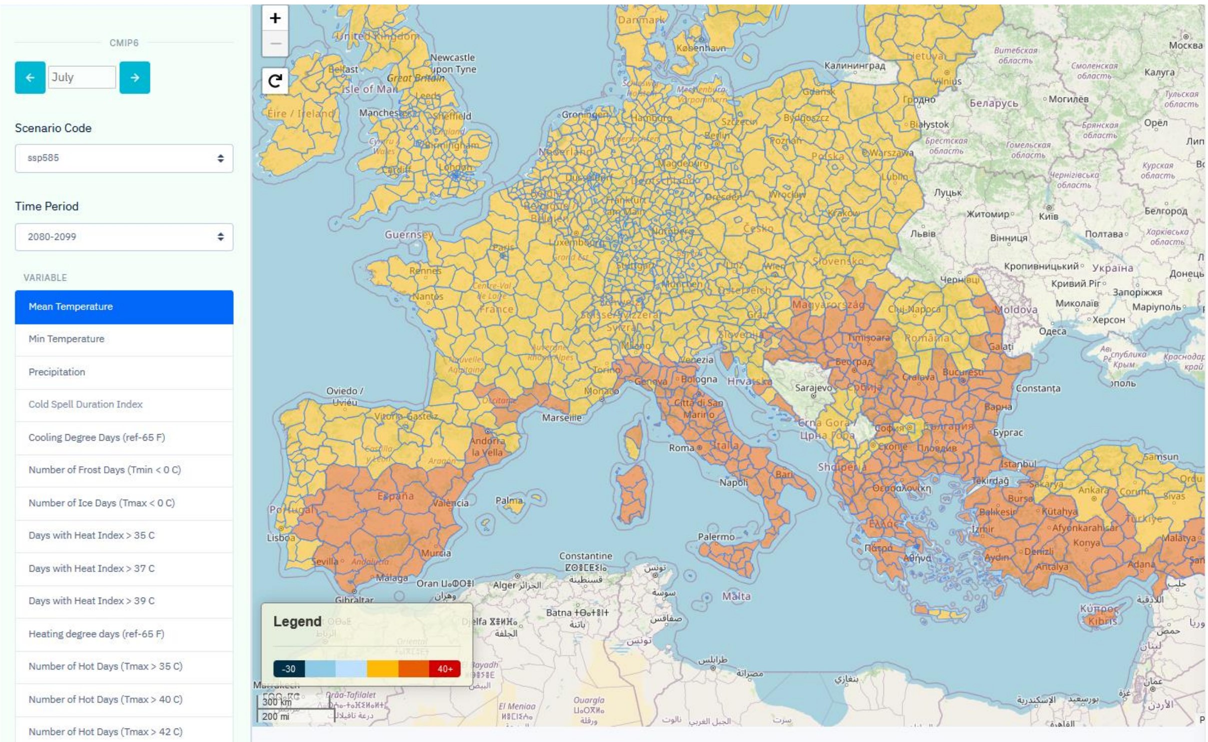

Figure 14: Interaction with a specific dataset.

The user can further interact with a loaded dataset by clicking on the map, at a region of interest. In this case, a label of the region pops-up, and a new panel appears with more info about the region, as demonstrated in Figure 15. The top of the panel gives specific info about the dataset and therefore varies with what is selected (and what is set to show in the back-end), as for example a timeseries graph for data that can have a temporal component, as well as other statistical properties. Under the specific info, there is a general tab that has customised useful climate-related information about the greater administrative level the region belongs, e.g., total greenhouse emissions. This information can be customised by the central dropdown box above the map window and also, in later versions of the service, more attributes for the region could be included (e.g., specific risks and vulnerabilities, adaptive capacity, adaptation measures/legislations in place and geographic characteristics)

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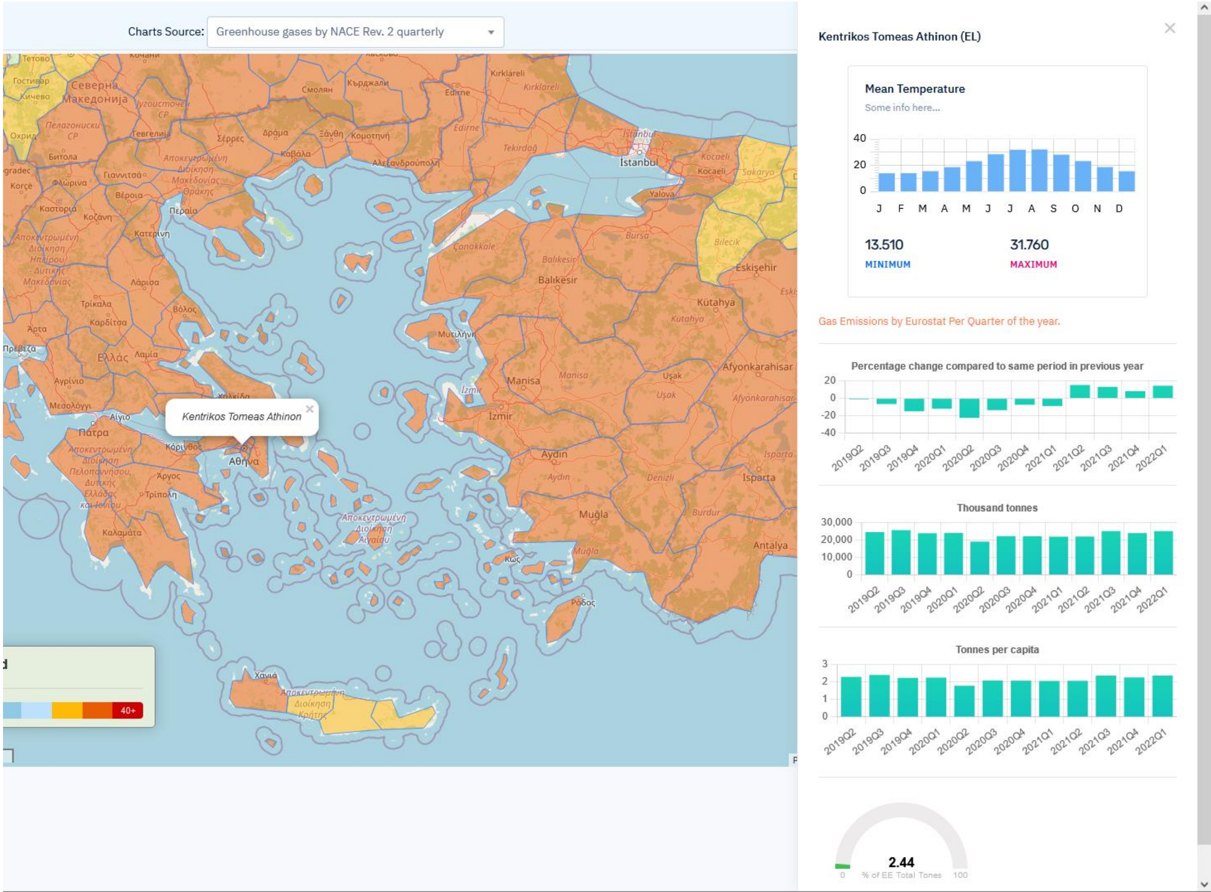

Figure 15: Interacting with a specific region after loading a dataset.

The “*Hot-spots”* button on the main user interaction panel fetches on click events the interface for the hot-spot mapping (Figure 16). Currently, the panel holds every dataset being generated in the back-end, but in the upcoming version of HIPS this panel will hold a wizard to interactively create hot-spots via the GUI in the front-end instead of creating them in the back-end. Also, a report will be generated for the user which can be saved locally.

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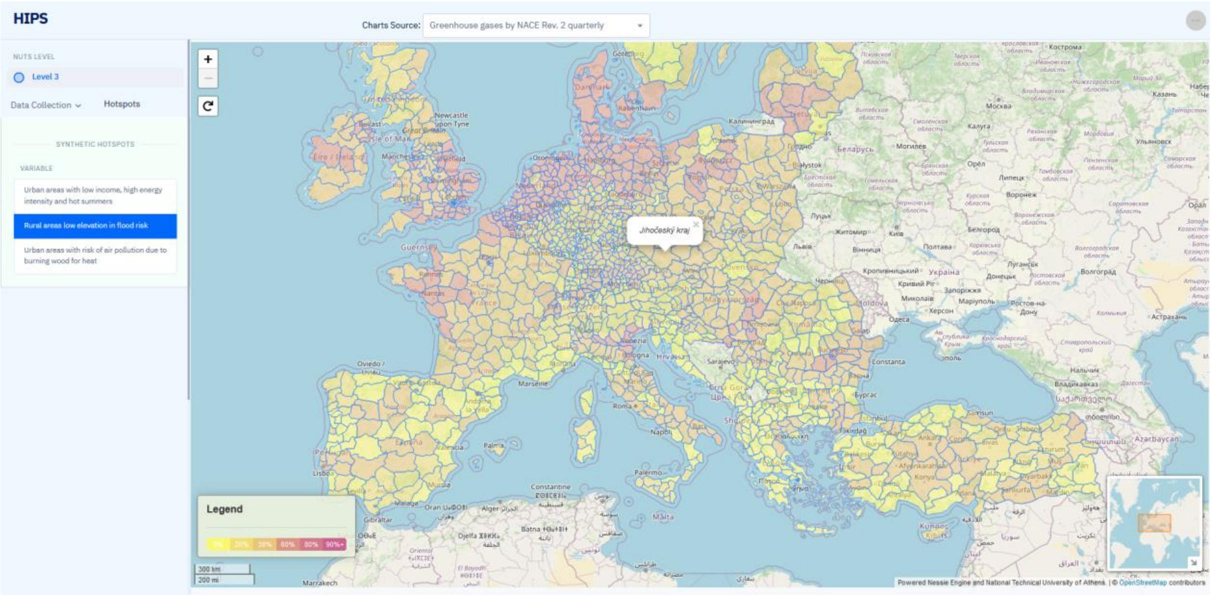

Figure 16: The Hot-spots panel for identification and prioritisation vulnerable regions against climate change impacts.

Finally, the account panel can be accessed by clicking the *avatar icon* on the right of HIPS interface (Figure 17). It holds information about the user (profile, role and settings) which can be used for authentication and offline storing analysis data.

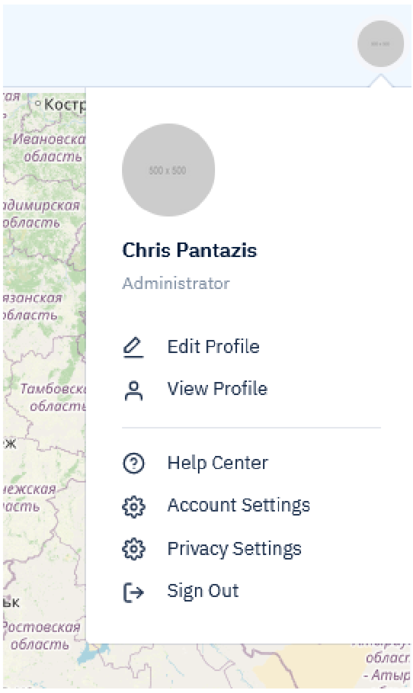

Figure 17: The account panel for each user.

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7 Conclusions, next steps, and further developments

7.1 Conclusions

The key objective of deliverable D3.2 is to develop an online tool and evaluation methods for assessing exposure, vulnerability and adaptive capacity of European regions to climate risk, based on the comprehensive metric and indicator framework developed in IMPETUS task 3.2. This is accomplished by the development of Hot-Spot Identification and Prioritisation Service or HIPS, It is a hot-spot identification and prioritisation service, that comprises a context broker and a database to gather and store a multitude of vastly different datasets ranging from climate projections to socioeconomic drivers, tools for curating datasets in a common regional format, methodologies and routines for analysing customisable hot-spots, a mapping service for visualisation and a Geographical User Interface (GUI) for user interaction. Stakeholders can set up customised hot-spot analysis by combining different future climate projections with other socio-economic indicators, leveraging the metric and indicator framework developed in IMPETUS task 3.2 and support decision-making and strategies about specific adaptation measures at a region. Targeted policies that consider the socioeconomic vulnerability characteristics and climate change impacts in addressing measures in a socially equitable and fair way are of paramount importance for the European Union's new Climate Adaptation Strategy.

7.2 Usage within the project and further developments

Within the IMPETUS project HIPS has a central role in identifying regions that are vulnerable to climate change and/or have less adaptive capacity, and as such it will be used throughout the project, interacting with many other tasks and work packages (WP). As such, HIPS will continue to get updated with new developments up to the end of WP3 in M42 and provide input to other tasks until the end of the project, at M48. The following contributions and updates are to be implemented as upcoming activities (described with a SMART – Specific, Measurable, Achievable, Relevant and Time-based – approach):

- Addition of more datasets and indicators in the database to use in synthesizing climate change hot-spots. These may include regional (i.e., specifically for European regions instead of global) projections of climatic (e.g., the European Coordinated Downscaling Experiment, EURO-CORDEX) and socioeconomic variables (e.g., projections of population according to shared socioeconomic pathways). The co-creation approach with demo-site stakeholders (task 1.2) and the multi-level policy assessment (task 1.3) will provide evaluation from end-users, from every demo site (WP4) and new dataset needs (along with customizations for data handling and visualizations at finer spatial scales) that will be provided by task 3.1 will be discussed to support them. These updates will be incrementally carried out until M42.
- Addition of more user interaction features in the front-end. These will include a graphical interaction element like a wizard to allow users a straight-forward customisation for hot-spots regarding their region, without scripting in the back-end, an interactive comparison tool of hot-spots emerging across different periods or by using different projections (or hot-spots from observations with hot-spots from projected scenarios), authentication layers for handling sensitive or confidential regional datasets, and possibly other features as well. End-user and stakeholder evaluation thought the project (relevant tasks 1.2, 1.3, and all WP4 tasks) will provide insight about these developments to address specific needs in the identification and prioritization toolset for climate vulnerable regions. The timeframe for addition of new user interaction features lasts until M42.
- HIPS will attain full REST compatibility and incorporation to RKB. Currently, HIPS is in a certain degree compatible with REST architectural style, because it is implemented in a way that front-end and back-end functionality is completely independent and their communication is based on HTTP requests. However, some minor additions have to be implemented in order for HIPS to be 100% REST compatible (for instance, the service's URLs paths must be standardised and create a more extensive documentation for the existing HIPS's API endpoints) and support the activities of WP2. Task 2.2 will provide input about the common data model and format

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utilized by HIPS to share information with other tools for knowledge sharing between the project and incorporation to the digital dimension of the RKB. The milestone for operationalizing this update is M36.

- Update the visualization schemes and graph capabilities. Task 2.5 will provide the requirements to support the high visualisation framework for public reach and impact for each demo site. Depending on the framework needs, proper customizations (e.g., colormap schemes, legend ranges, labels) for datasets and specific graphics capabilities may be implemented, by M36.
- Develop the Regional Climate Resilience Footprint Tool (RCRFT) as an interconnecting HIPS module. RCRFT is a tool developed within task 3.4, that will allow the self-assessment of a region's resilience against climate change, according to a suitable customised set of indicators (from task 3.2). HIPS is a service that can provide the basis for this assessment. RCRFT can operate as a module to HIPS, gathering the required data for a specific region from Nessie, and performing its assessment subsequently. The development will be finalized by M24.
- Provide input for task 3.6. HIPS is valuable for task 3.6, as it can be utilized for hot-spot analysis for regional vulnerability as a first assessment for the prioritisation of adaptation pathways and provide its rich database as the major repository for the intense data requirements for the scenario planner of the task. Some developments for the interoperability of the task 3.6 tools with HIPS may be needed. M36 marks the end of task 3.6.
- Provide input to WP5 tasks for adaptation pathways and innovation packages. HIPS is a valuable input, at least as a conversation starter for every demo-site (WP4) and the hot-spots generated with it will be part of the workflow towards adaptation pathways, within task 5.1 and task 5.3. M48 marks the end of these tasks.
- Provide input to the WP6 to boost the projects impact. HIPS is one of the tools that will be used for demonstrating IMPETUS solutions and creating an exploitation plan in WP6 (task 6.2 and task 6.3), which end in M42 and M48.

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