## Europe’s Climate Map for Students


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Author: Manolis Voutsakis
EPU-NTUA

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# 1. Introduction

The increasing number of natural disasters in recent years has driven the creation of 'VR4Clima', a project led by partners from regions heavily impacted by climate change. The project aims to inspire future citizens to become environmentally conscious, make sustainable choices, and minimise their carbon footprint. By using Virtual Reality (VR) and 3D design in education, 'VR4Clima' allows students to explore serious gaming, create their own 3D models, and build their STEAM skills. Teachers and students will also benefit from new technologies, which encourage creative, modern learning experiences.

One of the project's key outcomes, is **'Europe's Climate Map for Students'**, a student-friendly map designed to help young learners understand Europe's climate zones and how they vary across different regions. The map uses bright visuals and simple classifications, making it easy for students to learn how climates affect weather, agriculture, biodiversity, and daily life. The project also helps students and educators learn about the fundamentals of climate science, including climate classification and the key risks posed by climate change in different regions.

Specifically, this document is structured into five major chapters. The current chapter serves as an introduction, outlining the document's purpose and its connection to the broader project. Chapter 2 defines key definitions essential for readers, particularly students, to better understand the topics discussed later. Chapter 3 explores the widely recognised climate classification systems and the development of modified systems, presenting an overview of methodologies used to categorise different climates. Chapter 4 focuses on the methodology adopted for this project. It begins by addressing concerns related to map design and the process of developing a simplified, student-friendly climate classification system. The chapter also outlines the map creation process in detail, covering tools used, the study area, spatial analysis, and the assignment process. It concludes with an overview of the final map, highlighting its features and advantages for young learners and educators. Finally, chapter 5 explains the key climate risks Europe is facing. It includes a student-friendly infographic that visually presents the climate risks for each climate zone, based on the map created.

# 2. Definitions

In this chapter, some key definitions that will be useful to students in understanding the topics covered later are briefly presented. By providing clear and simple explanations, this section aims to give readers the background knowledge needed to engage with the more detailed discussions on climate systems and their impact in the following chapters.

## 2.1. Weather

Weather refers to the short-term conditions of the atmosphere in a particular place, including temperature, precipitation, humidity, wind, and visibility. It changes from day to day and can vary significantly even within the same region (Whitfield & Stahl, 2008).

## 2.2. Climate

Climate, on the other hand, is the average weather conditions in an entire region over a long period (30 years or more) (Whitfield & Stahl, 2008). It includes typical temperatures, precipitation levels, and seasonal variations.

### 2.3.1. Macroclimate

The overall climate of large areas, such as continents or entire countries. Climate is determined by the temperature, precipitation, humidity and wind speed in a region. These characteristics are influenced by topography and natural factors as latitude, proximity (water access/ distance from the sea), altitude. Climates could be classified into several zones, as analysed in the following chapters. In summary, using a customised version of the well-known Köppen-Geiger climate classification, they can be viewed as (Cui et al., 2021):

- **Tropical**: These areas are warm all year round and often have a lot of rain, like the rainforests in South America.
- **Dry (Arid)**: Places with very little rain, often deserts like the Sahara. These areas can be very hot during the day and chilly at night.
- **Temperate**: These places have warm summers and cold winters, like we experience in a large part of Europe. They often have a mix of sunny and rainy days.
- **Cold (Snow/ Continental)**: Found in places with hot summers and cold winters, often further from the ocean, like some parts of Eastern Europe.
- **Polar**: These areas, like the North and South Poles, are very cold all year round, with snow and ice covering the ground.

Each of these zones affect the types of plants, animals, and the way people live in those areas. In Europe, not all the climate types listed above are observed, therefore the classification may vary, as described in the subsequent chapters.

### 2.3.2. Local Climate

Local climate refers to the climate of a specific area like a city, a valley or a coastline, influenced by geographical features such as elevation, proximity (water access/ distance from the sea), soil, vegetation or the presence of mountains, water bodies, and urban areas. At a scientific level, local climates are categorised into various types through classification systems as the LCZ (Local Climate Zone) (Stewart & Oke, 2012) or the LULC (Land Use and Land Cover) (Vinayak et al., 2022). By simplifying this analysis, they can be roughly classified into broad zones as:

- **Urban**: Places as cities and towns, which they can be warmer than the surrounding countryside (rural) areas due to human activities (buildings, roads, etc.) and vehicle emissions.
- **Coastal**: Areas close to the sea often have milder temperatures and more humidity, avoiding extreme heat in summer and extreme cold in winter.
- **Rural/ Agricultural**: Open countryside or farmland areas often used for crop production and raising animals. They often have bigger temperature changes because there are fewer trees to provide shade and cooling.
- **Forest**: Areas with lots of trees can be cooler and more humid because the trees provide shade and hold moisture in the air.

For example, the hot urban local climate of Athens city centre has different conditions from the Mount Olympus, where the local climate is cooler and wetter.

### 2.3.3. Microclimate

A localised climate that differs from the main regional climate. Within a climate region, the climate may vary from one place to another. These specific small areas with their small variations are called microclimates, such as a garden, an area around a tree or a building, a schoolyard or a playground. Microclimates are created by different factors, leading to variations in temperature, humidity, wind speed and other conditions in a small area. These factors are influenced by topography, soil, vegetation and the presence of artificial structures (human activity) (*UC: Division of Agriculture and Natural Resources* , n.d.). For instance, they can be observed through these customised types:

- **Urban Corners**: In cities, some areas such as narrow streets or spaces between buildings remain warmer, as they are protected from the wind and trapping heat.
- **Sunny Areas**: Spots that get a lot of direct sunlight, like open fields or south-facing gardens, are usually warmer and drier.

- **Shady Areas:** Places that receive less sunlight, such as under a tree or beside a tall building, tend to be cooler.
- **Humid Areas**: Places close to water sources, such as ponds, rivers, or lakes, tend to have higher humidity and cooler temperatures, which can benefit certain plants.

Using microclimates as an observational tool helps explain why some plants might grow better in one part of a garden than another (*UC: Division of Agriculture and Natural Resources* , n.d.). A great example is the 'Garden Site Microclimate Evaluation Form' a spreadsheet crafted by UCCE Marin Master Gardeners, which helps to analytically observe the landscape and determine the location of garden microclimates. With this knowledge, it ensures the right plant is placed in the right location (Garden Site Microclimate Evaluation Form, n.d.).

# 3. Climate Classification Systems

Several systems have been developed to classify climates, each offering unique approaches and insights. This chapter highlights the most significant and widely used systems, providing an overview of their characteristics and contributions to climate studies.

## 3.1. Köppen–Geiger Climate Classification (Köppen Climate Classification)

One of the most detailed visual representations of a climate map is often presented through the Köppen-Geiger classification. The Köppen-Geiger climate classification system is a widely recognised and accepted method for categorising global climates.
The system divides climates into five main groups (A, B, C, D, and E), each representing a broad climatic type. Each main group is further divided into subtypes based on seasonal temperature and precipitation patterns. Below is a breakdown of the main groups and the description of their subcategories (Chen & Chen, 2013; Peel et al., 2007; Rubel & Kottek, 2010):

- **Group A: Tropical Climates**
  In this type of climate, the average temperature remains above 18°C every month of the year. Annual precipitation typically surpasses 1500 mm.
  - Subtypes:
    - Af (Tropical Rainforest): Wet climate, without dry season, precipitation occurs every month (rain throughout the year).
    - Am (Tropical Monsoon): Short dry season, followed by an extended wet season influenced by monsoon winds.
    - Aw (Tropical Savanna): Distinct tropical wet and dry seasons. Dry winters (Aw) or dry summers (As).
- **Group B: Arid (Dry) Climates**
  In arid and semi-arid climates, precipitation levels are notably low, generally ranging between 25 and 200 mm annually. These climates are more influenced by the characteristics of precipitation rather than temperature. The evaporation exceeds precipitation.
  - Subtypes:
    - BWh (Hot Desert): Extremely arid, very high daytime temperatures and significant cooling at night. Average annual temperature > 18°C.
    - BWk (Cold/ Cool Desert): Arid with colder temperatures, typically found at higher elevations or latitudes. Average annual temperature <18°C.
    - BSh (Hot Semi-Arid): Semi-arid (steppe) with hot temperatures. Average annual temperature > 18°C.

        - BSk (Cold/ Cool Semi-Arid): Semi-arid (steppe) with cooler temperatures. Average annual temperature <18°C.

- **Group C: Temperate (Mild Mid-Latitude) Climates**
  Temperate climates typically experience a broader range of temperatures throughout the year. These variations are influenced not only by latitude but also by factors such as ocean currents, prevailing wind directions and altitude.
    - Subtypes:
        - Cfa (Humid Subtropical): No dry season, mild winters, hot and humid summers.
        - Cfb (Oceanic and Subtropical Highland): No dry season, cool winters and mild summers, often influenced by oceanic air masses. Consistently heavy rainfall throughout the year.
        - Cfc (Subpolar Oceanic): Higher in latitude or elevation to the Oceanic, these areas still have mild winters, but cooler summers.
        - Csa/ Csb (Mediterranean): Dry summers and wet winters, Csa has hot summers, while Csb has warm/mild summers. It is mainly influenced by the Mediterranean Sea and the Sahara Desert.
- **Group D: Continental (Cold Mid-Latitude) and Subpolar Climates**
  Continental climates are characterised by at least one month with an average temperature below 0 °C and at least one month with an average temperature above 10 °C. In subpolar types of winters are exceptionally cold, accompanied by strong winds and frequent snowstorms.
    - Subtypes:
        - Dfa/ Dfb (Humid Continental): No dry season, hot (Dfa) or warm/mild (Dfb) summers and cold winters.
        - Dwa/ Dwb (Monsoon-Influenced): Winter dry season with similar temperature variations to Dfa/ Dfb.
        - Dfc/ Dfd (Subpolar): No dry season, short and cool summers, long and extremely cold winters.
- **Group E: Polar Climates**
  These climates are characterised by an average monthly temperature below 10 °C throughout the entire year.
    - Subtypes:
        - ET (Tundra): Average warmest month temperature between 0°C and 10°C.
        - EF (Ice Cap): Average temperature of all months < 0°C all year round, found in Antarctica and Greenland.

As previously mentioned, the criteria for this categorisation are the average monthly and annual temperature and the average monthly and annual precipitation. The first letter defines the climate group, the second letter represents the precipitation and the third designates the temperature (Peel et al., 2007; Rubel & Kottek, 2010)). The meaning of the letters used in the Köppen-Geiger classification codes:

| **1st Letter** | **2nd Letter** | **3rd Letter** |
|---|---|---|
| **A (Tropical)** | f (Rainforest, fully humid) | |
| | m (Monsoon) | |

| | | |
|---|---|---|
| | w (Savanna, dry) | |
| | s (Savanna, dry) | |
| **B (Dry)** | W (Desert (Arid)) | h (Hot arid) |
| | S (Steppe (Semi-Arid)) | k (Cold arid) |
| **C (Temperate)** | w (Dry winter) | a (Hot summer) |
| | f (No dry season, fully humid) | b (Warm summer) |
| | s (Dry summer) | c (Cold summer) |
| **D (Continental)** | w (Dry winter) | a (Hot summer) |
| | f (No dry season) | b (Warm summer) |
| | s (Dry summer) | c (Cold summer) |
| | | d (Very cold winter) |
| **E (Polar)** | T (Polar Tundra) | |
| | F (Ice cap, Polar Frost) | |

*Table 1: The symbols of Köppen-Geiger climate classification*

## 3.2. Thornthwaite Climate Classification

The Thornthwaite system classifies climates based on moisture availability and potential evapotranspiration (evaporation from the soil and transpiration from vegetation), which represents both precipitation effectiveness and thermal efficiency (PET). Thornthwaite divided the world into five humidity regions (*Thornthwaite Climatic Classification - UPSC - UPSC Notes » LotusArise*, n.d.):

| **Letter** | **Humid Region** | **Special Type of Vegetation** | **P/E index** |
|---|---|---|---|
| A | Very Humid (Wet) | Rainforest | >127 |
| B | Humid | Forest | 64-127 |
| C | Semi-Humid (Subhumid) | Grassland | 32-63 |
| D | Semi-Dry (Semi-Arid) | Steppe | 16-31 |
| E | Dry (Arid) | Desert | <16 |

*Table 2: Thornthwaite climatic classification*

Based on the P/E index (P/E ratio=total monthly precipitation/ Evapotranspiration P/E index= sum of 12-month P/E ratio).
This system is used mainly for ecological and hydrological studies because it provides insights into water availability and vegetation types. It has been criticised for its complexity and it is less commonly used outside environmental studies.

## 3.3. Modified Classification Systems

Due to complexity of the above most systems, simpler and modified versions of climate classification methods are often used, especially for educational reasons. Some of them are:

- **Biomes-Based Classification:** Using biomes (e.g., rainforest, desert, tundra) as a way to classify climate types can be easy and effective. Each biome is associated with specific climates and vegetation, making it easier for students to visualise and understand the relationships between climate, geography, and ecosystems. It can be used a classification based on the most recognised biomes, as (Rohli et al., 2015):
    - Tropical Rainforest
    - Grassland
    - Desert
    - Subtropical Scrub and Woodland

  - Subtropical and Mid-latitude Forest
  - Boreal
  - Tundra
  - Ice Cap/ Highland
- **Trewartha Climate Classification:** It is an adaptation of the Köppen system, aiming to be more descriptive and specific for regions with seasonal variations. This classification is especially valuable for breaking down climate zones in middle latitudes. It categorises climates into (Cui et al., 2021):
  - Tropical climate
  - Dry (Arid and Semi-Arid) climate
  - Subtropical climate
  - Temperate climate
  - (Cold) climate
  - Polar climate
- **Simplified Köppen-Geiger Classification:** The original Köppen-Geiger climate classification system can be challenging to memorise, especially for younger learners. To make it more accessible, several student-friendly (simplified/ modified) versions have been developed. A broader classification provides students with a clear framework for understanding climate zones without the complexity of additional symbols and intricate subcategories. A modified Köppen-Geiger version either at the global scale or in the study of a specific continent, would include customised climate categories.

As detailed in the following chapters, a simplified student-friendly version of the Köppen-Geiger classification was specifically adapted to create a climate map of Europe for school students. This adapted system still retains the essence of the climate types while avoiding excessive detail. This system was chosen for its clear structure, which classifies climates focused on broad categories without complex subcategories and for its ability to support visual learning with maps and colours, making it especially suitable for young learners.

# 4. Methodology

## 4.1. Concerns & Map Design Process

In creating a climate map, the primary concerns include simplifying the complex climate classification systems, making the information age-appropriate, and selecting a visual representation that is both educational and engaging for school students. Furthermore, it is difficult within a static map that includes all the European countries to capture in detail all the climate differences. Prior to the development of this map, an analysis was conducted on various Köppen-Geiger climate maps of Europe ((*Esri, USGS | ArcGIS*, n.d.; *Köppen-Geiger Explorer*, n.d.), which served as foundational sources of inspiration for its creation (Beck et al., 2018, 2023; Peel et al., 2007). A common feature among these maps was their lack of simple and accessible information that could be easily understood by young learners. Even those offering interactivity and supplementary analyses it was not easy to provide an immediate understanding for young learners, making it challenging for them to retain the essential information regarding which climate zone a particular area/ region in Europe belongs to. This was due to an excessive number of categories, whereas children can typically handle and retain only 4 to 6 categories effectively (Bobek & Tversky, 2016; Martinelli & Raykov, 2021; Xu et al., 2022)Thus, the approach to make the Köppen-Geiger system student-friendly was guided by the intended educational experience and knowledge that students should acquire when observing this map. Additionally, an

important consideration influencing the map's design was the way the VR game is expected to be played. The map is separate from the game and is not involved in its implementation, but it could serve as a valuable tool for students to consult before playing. For effective engagement, it is crucial that children are able to understand how to adjust their choices based on the specific climatic conditions of each area in order to promote both the sustainability and the resilience of their schoolyard against a natural disaster (aiming to minimise possible damages).
The initial objective was to create a map of Europe’s microclimates. However, it proved challenging to represent this on a large scale. Thus, the topic was revised to focus on mapping the local climates of Europe. Categorising and colour-coding each local climate zone according to established, scientifically valid classifications would not effectively help students easily grasp the differences between regions. In the below LCZ (Local Climate Zones) map, different shades of green show types of vegetation, blue represents water areas, black refers to mountainous places, red and orange mark urban zones and buildings (Figure 4.1) (Demuzere et al., 2021). In case that the map was interactive with a zoom option, the learner could access this detailed information. However, without zoom, it can lead to misunderstanding as it is challenging to distinguish minor details between local climate types on a large scale (Figure 4.2 and Figure 4.3). For example, a student might assume that Paris and Athens share the same climate due to their similar red shading on the map, indicating an urban local climate. However, their climate characteristics differ significantly. The urban local climate of a North-western European city varies distinctly from that of a Southern European city or region. The important point here is that, despite both being categorised as ‘urban’ cities in different regions (Northwestern Europe, like Paris, versus Southern Europe, like Athens) have unique climate traits due to their geographical locations. Factors such as latitude, regional weather patterns, and proximity to large bodies of water contribute to these differences. Consequently, even though both cities might be marked as having an ‘urban local climate’, Paris has a cooler and wetter climate, typical of Northwestern Europe, while Athens experiences a warmer and drier Mediterranean climate, characteristic of Southern Europe.

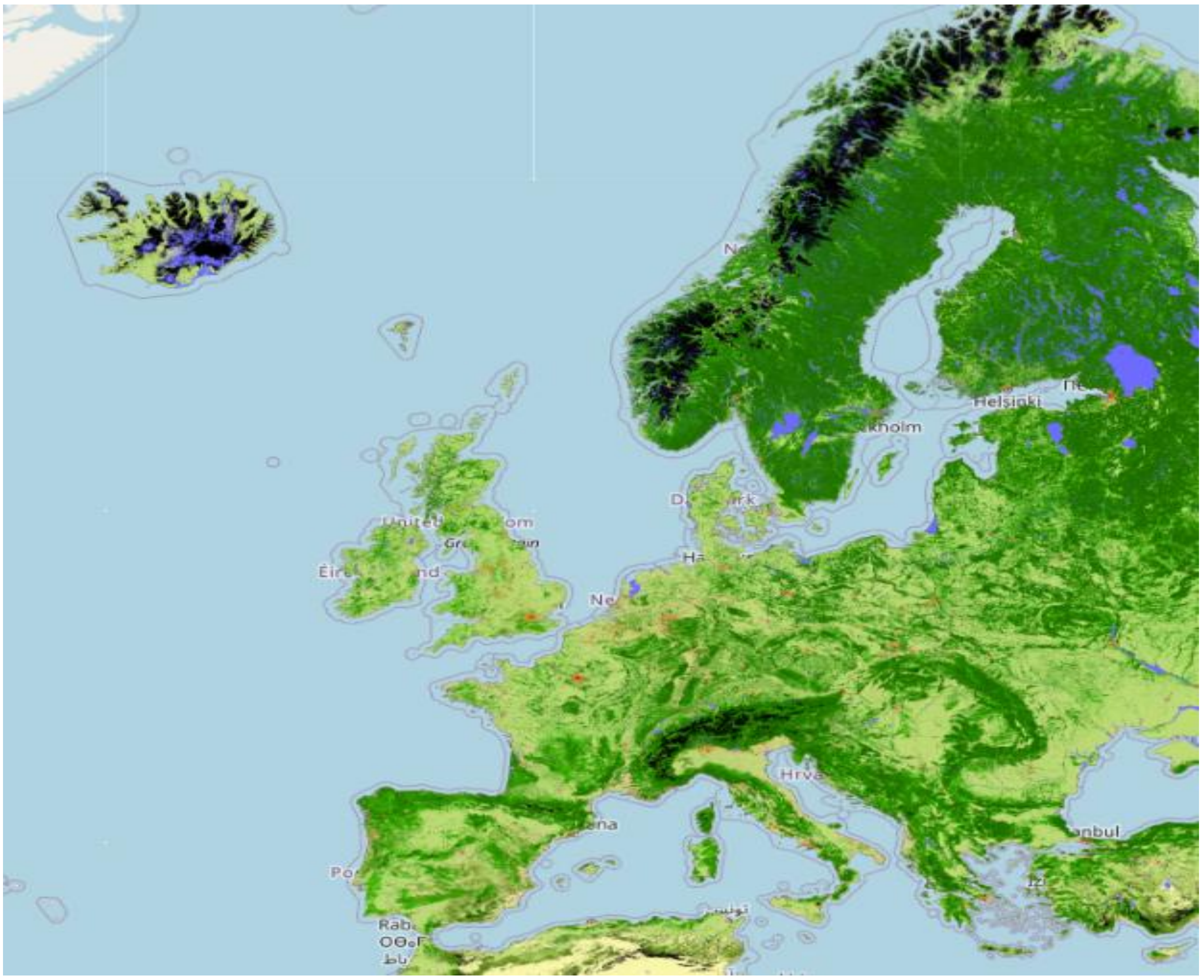


*Figure 4.1: Europe (LCZ map)*

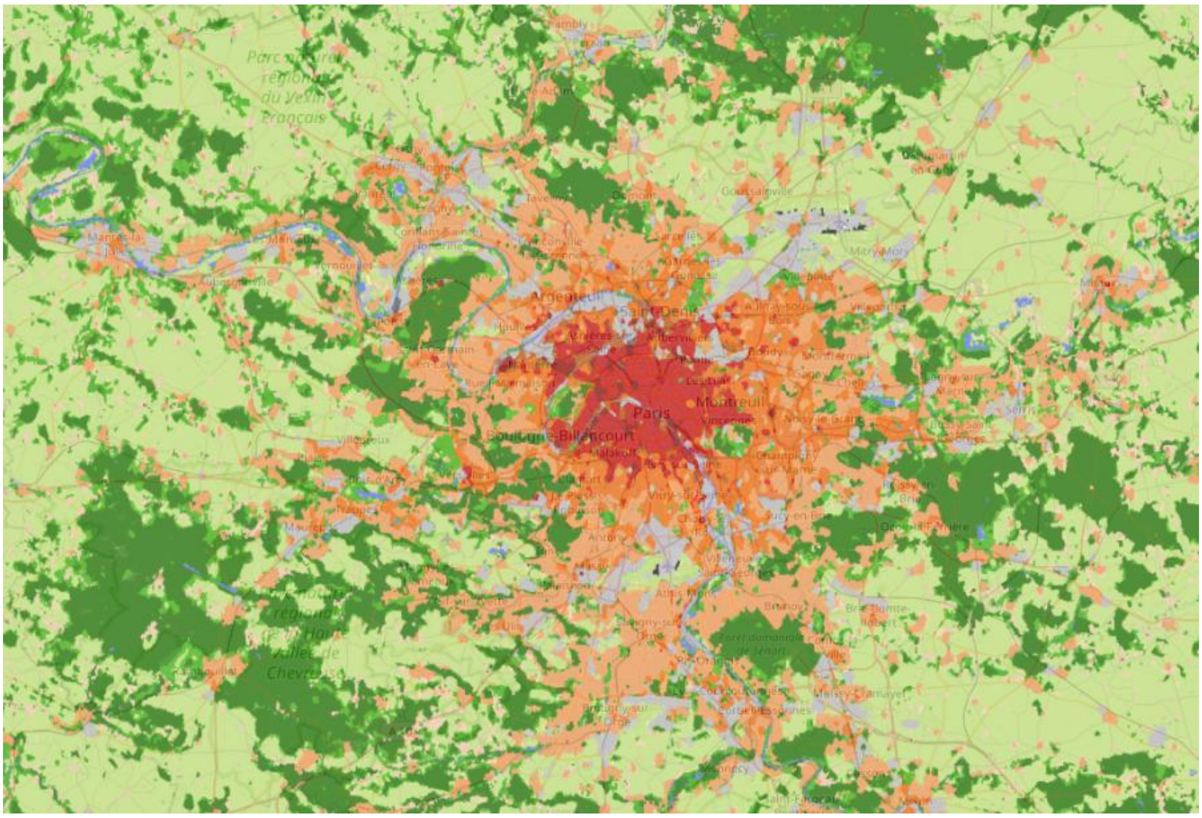


*Figure 4.2: Local Climate Zones of Paris (LCZ map)*

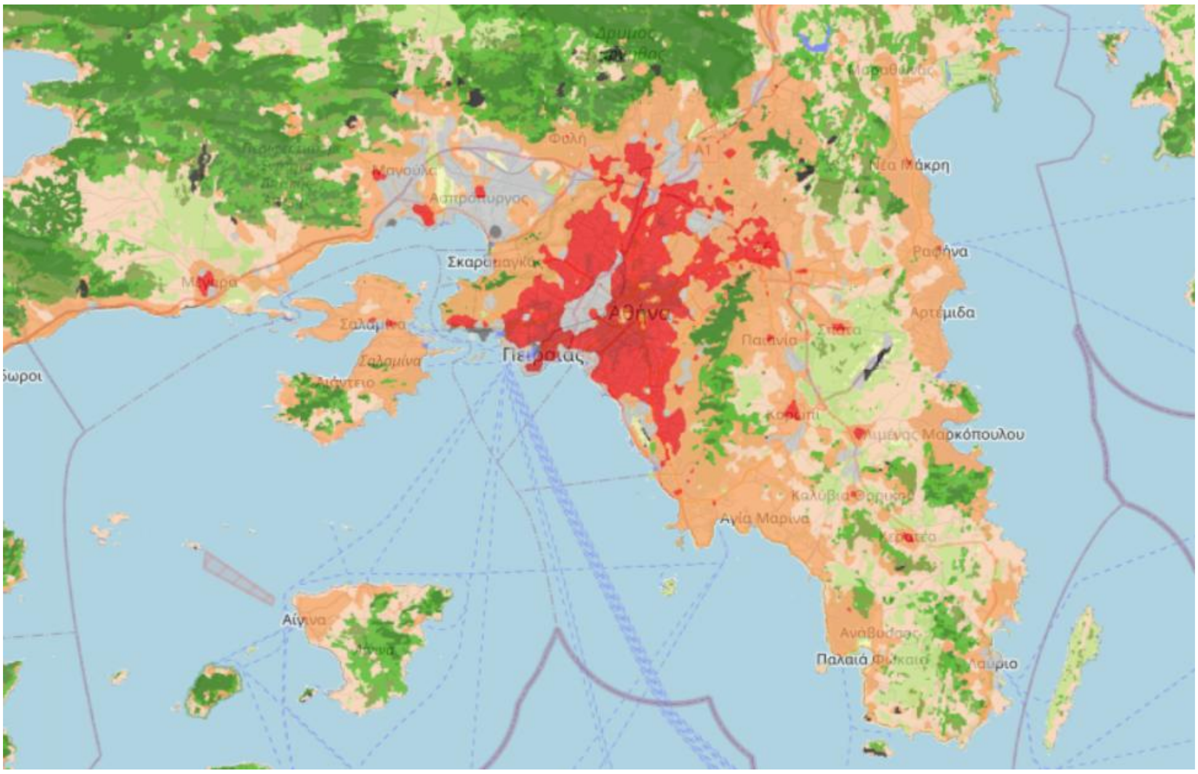


*Figure 4.3: Local Climate Zones of Athens (LCZ Map)*

Ultimately, it was decided to create a climate map (global climate) of Europe in order to improve the overall outcome. As noted in previous chapters, the original Köppen-Geiger system- a detailed classification that categorises climates based on temperature, precipitation, and seasonal patterns- is highly specific and intricate. If applied directly, it would produce a map with excessive detail, making it hard for students to grasp broader, large-scale climate trends across Europe (Figure 4.4)(*Esri, USGS | ArcGIS*, n.d.). Therefore, a student-friendly (simplified/ modified) version of Köppen-Geiger's system was used, allowing for clearer distinctions between regions and enabling students to identify and compare climates more easily.

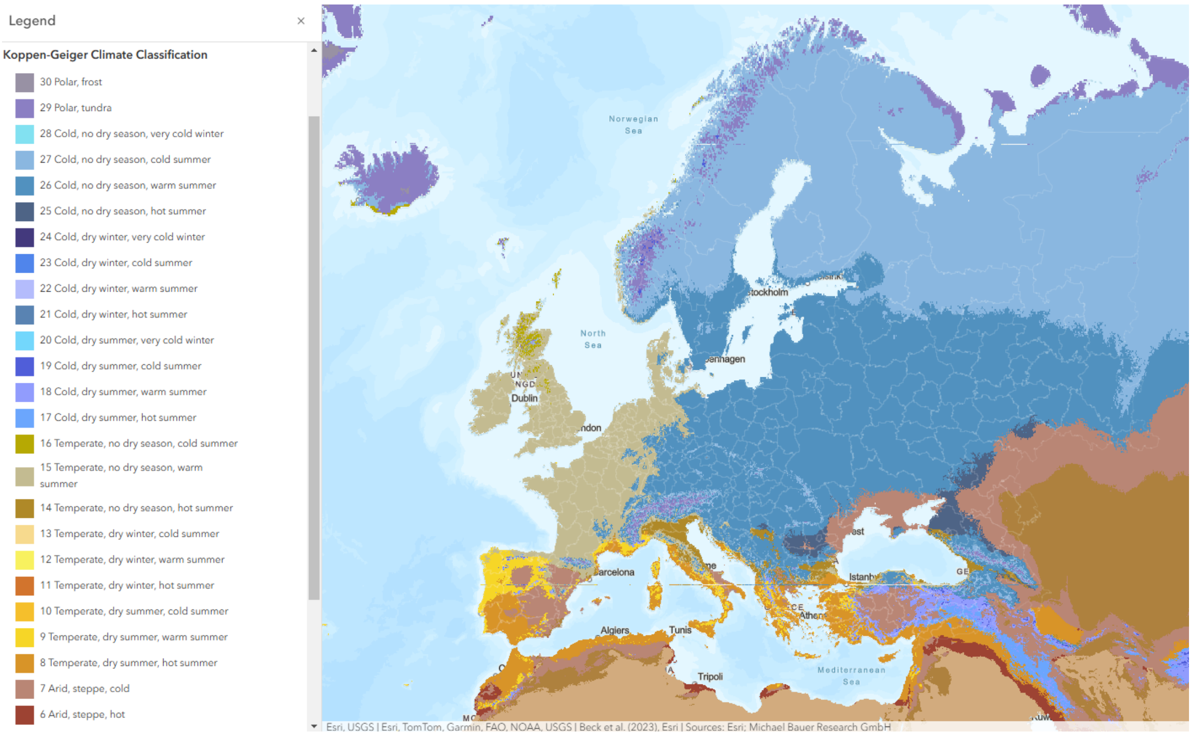


*Figure 4.4: Europe's climate map (Köppen–Geiger climate classification)*

## 4.2. Student-friendly Climate Classification System

Taking the above considerations into account, the Köppen-Geiger climate classification system was modified in order to be employed in this analysis. The original 12 Köppen-Geiger climate categories (classes) observed in Europe, were modified and consolidated into six (6) broader, more generalised categories. Each climate type (class) has been assigned a specific colour to enhance the map's readability and to help students differentiate the climate zones easily. The decision to reduce the original 12 Köppen-Geiger climate categories to six (6) broader groups serves the learning needs of young students, who are exposed to a meaningful range of climates that represent Europe's geographic diversity (Clark et al., 2011; Mestre & Ross, 2011). This number was carefully chosen to strike a balance between too little and too much information. Fewer than six (6) categories would likely merge distinct climates into overly broad groups, which could blur important differences, such as those between Mediterranean and Oceanic climates. More than six (6) categories could add unnecessary complexity, making it harder for younger students to recognise, remember and distinguish the information. A six-colour model provides a manageable number of visual designs that children can quickly learn to associate with specific climates (Xu et al., 2022).

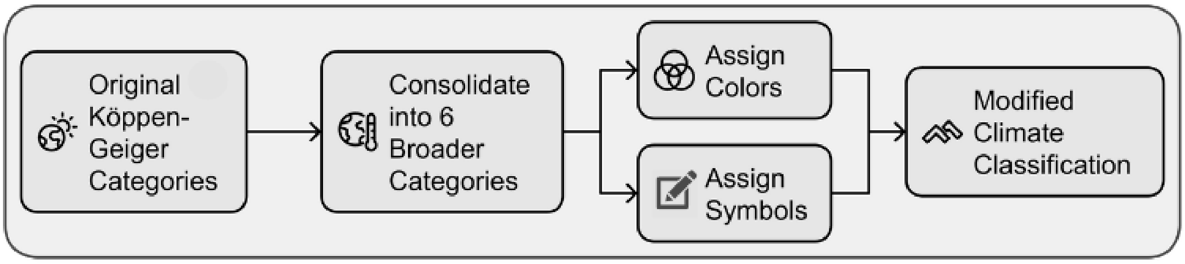


*Figure 4.5: Process of creation a Modified (student-friendly) Climate Classification*

The classification was initially based on the broader Köppen-Geiger climate groups to which each region belongs. In Europe, where tropical climates are absent, this resulted in four (4) primary categories (Dry (Arid), Temperate, Continental and Polar). However, this number was considered too small, as it led to the loss of significant details about regional climatic variations. To solve this, average precipitation (monthly and annually) was added as a second criterion, increasing the categories to five (5) (Dry (Arid), Mediterranean (Temperate), Oceanic (Temperate), Continental and Polar). While this was suitable for teaching school students, the visual result still had some limitations. For instance, the large expanse of a single continental climate across central and northern Europe created an overly generalised representation, which could potentially confuse viewers in the future. To improve the educational value of the map and provide a more accurate representation, the 'Continental' climate category was further divided into two (2) subcategories (Cold (Continental) and Subpolar), based on average temperature (monthly and annually). Specifically, the 'Dry (Arid)' category encompasses the two (2) primary dry categories according to Köppen-Geiger, observed in European regions as 'BSk (Cold/Cool Semi-Arid)' and 'BSh (Hot Semi-Arid)'. The 'Mediterranean (Temperate)' category includes the 'Csa (Hot Summer Mediterranean)' and 'Csb (Warm Summer Mediterranean)' types. The 'Oceanic (Temperate)' category includes the 'Cfa (Humid Subtropical Oceanic)', 'Cfb (Oceanic and Subtropical Highland)' and 'Cfc (Subpolar Oceanic)' types. The 'Cold (Continental)' category incorporates the 'Dfa (Hot Summer Humid Continental)' and 'Dfb (Warm Summer Humid Continental)' types. The 'Polar' category includes only the 'ET (Tundra)' type. This adjustment allowed for a more precise and visually balanced depiction of Europe's diverse climates, making the map a more effective tool for teaching and learning.

In the table below, the student-friendly climate classification is presented, detailing each climate zone alongside its corresponding colour:

| A/A | Class Name | Köppen-Geiger Code | Colour | Symbol |
|---|---|---|---|---|
| 1 | Dry (Arid) | BSk, BSh | Red | Sun |
| 2 | Mediterranean (Temperate) | Csa, Csb | Yellow | Olive Branch |
| 3 | Oceanic (Temperate) | Cfa, Cfb, Cfc | Green | Rain Cloud |
| 4 | Cold (Continental) | Dfa, Dfb | Purple (Magenta) | Pine Trees |
| 5 | Subpolar | Dfc, Dfd | Blue | Snowflake |
| 6 | Polar | ET | Light Blue (Cyan) | Ice Cube |

*Table 3: Student-friendly Köppen-Geiger Climate Classification*

These colours are based on RGB model (primary colours) and symbols were thoughtfully selected to simplify and enhance learning for young students (Bobek & Tversky, 2016; Clark et al., 2011; Xu et al., 2022). Each colour is associated with a specific climate type, creating a visual connection that reinforces key characteristics. The symbols are chosen from a source without copyright infringement (*Flaticon: Free Icons and Stickers*, n.d.). By connecting colours and symbols to familiar images and sensations (such as warmth or coolness), students can intuitively understand the characteristics of each climate zone. This visual approach promotes interactive learning and helps students to categorise climates using memorable, relatable cues(Clark et al., 2011; Cromley & Chen, 2023; Mestre & Ross, 2011; Raiyn, 2016).

- **Dry (Arid)**: Characterised by low precipitation. These regions experience high temperatures during the day and cooler nights. In these areas evaporation exceeds precipitation (evaporation > precipitation). Vegetation is sparse, and deserts or semi-deserts are common. In Europe, this climate is mainly found in southern Spain and parts of Greece.
    - Red colour was selected as it is bold and warm, that can suggest heat and dryness, which aligns well with the idea of deserts and arid regions.
    - As a symbol of 'Dry (Arid)' climate was selected the 'sun'. It represents hot, dry weather, helping students instantly think of sunny, dry places.
- **Mediterranean (Temperate):** Defined by hot, dry summers and mild, wet winters. This climate type is found in southern Europe, especially along the Mediterranean coast (e.g., Portugal, Spain, Italy, Greece). It supports a variety of crops like olives and grapes due to its distinct seasonal rainfall pattern.
    - Yellow colour was chosen since it reminds the warmth atmosphere and the sunlight which suits to Mediterranean regions.
    - As a symbol of mediterranean climate was selected the 'olive branch'. It is commonly found in Mediterranean countries like Greece and Italy, making it an easy way for students to connect the symbol to the Mediterranean climate.
- **Oceanic (Temperate):** Found in coastal areas with mild temperatures year-round, characterised by frequent rainfall. Summers are cool and humid, winters are mild, with little temperature variation throughout the year. This climate is common in western Europe, including the UK, Ireland, and parts of France.
    - Green is associated with lush vegetation which are common in places with oceanic climate due to frequent rain.
    - As a symbol of 'Oceanic' climate was selected the 'rain cloud', helping students to think of rainy weather, a characteristic feature of regions like the UK and Western Europe.
- **Cold (Continental):** Typically found in inland regions, this climate features hot summers and cold long-lasting winters, with significant temperature differences between seasons. Precipitation is moderate, occurring throughout the year but often more in summer. Natural vegetation is usually in the form of grassland, but these areas are heavily farmed. It is present in central and eastern Europe, such as in Germany, Poland, and Latvia.
    - Purple (Magenta) is a strong colour that can signify the cold climate, making it memorable.
    - The 'pine trees' symbol was chosen to represent the 'Cold (Continental)' climate, reflecting the forest types commonly found in these regions.

- **Subpolar:** Marked by long, cold winters and short, cool summers. Precipitation is low to moderate. Subpolar regions experience harsh conditions, with the ground often covered in snow for most of the year. The vegetation is dominated by coniferous forest, farming is almost non-existent. This climate is typical of northern Europe, especially in parts of Sweden, Norway, and Finland.
    - Blue colour symbolises colder temperatures and icy landscapes, characteristic of subpolar climate.
    - As a symbol of 'Subpolar' climate was selected the 'snowflake', offering a clear representation of snow and cold that is easy for students to understand.
- **Polar:** Defined by extremely cold temperatures year-round. Precipitation is low, mostly falling as snow. This climate supports little vegetation, due to the harsh conditions and permafrost (any ground that remains completely frozen for at least two years straight). Found in the far north of Europe, such as in Iceland.
    - Light blue (Cyan) colour suggests the feel of freezing, extremely cold conditions, aligns well with polar climate.
    - The 'ice cube' was chosen as a symbol for the 'Polar' climate, providing a simple and direct image that relates to ice and extreme cold.

## 4.3. Map Creation Process

For the creation of the map, the climate for the period 1991-2020 was examined, based on existing climate data from scientific studies, meteorological services, and websites (Beck et al., 2018, 2023; Peel et al., 2007; *World Bank Data | Climate Change Knowledge Portal*, n.d.). The extracted data was based on two straightforward, measurable factors: temperature variations -defined by the average monthly temperatures throughout the year- and monthly and annual precipitation averages. The goal was to identify the dominant climate category for each area according to the Köppen-Geiger climate classification. This was not clear for all areas, so it was necessary to cross-reference climate data from Köppen-Geiger maps or collections of data from meteorological websites. The data assignment process is analysed in the following subchapters. The map went through several rounds of testing and improvement, with adjustments to ensure that the colours were distinct and accessible for students. The final map is static (2D) in a high-resolution format 1024x768 pixel.

### 4.3.1. Map Creation Tool

The climate map was produced using 'Datawrapper' a user-friendly, open-source, web-based tool developed by 'Datawrapper GmbH', that allows for customisation in map appearance and region selection, making it particularly suitable for representing climate zones in Europe (*Datawrapper*, n.d.). This tool was chosen for its simplicity and the ability to produce high-quality visuals that are ideal for educational purposes. The specific basemap utilised in Datawrapper was the 'Europe NUTS2 2021' map, which provides subdivisions across Europe that align with the NUTS2 (Nomenclature of Territorial Units for Statistics) framework (*Europe » NUTS2 (2021) - Datawrapper*, n.d.).

### 4.3.2. Study Area & Spatial Analysis

The study area is Europe with a classification for regional divisions by the NUTS2 (Nomenclature of Territorial Units for Statistics). This type provides a standardised framework for examining spatial 283 regions. It was chosen for its detailed but not overly complex geographic divisions, helping students understand regional differences without being overloaded with information.

The NUTS is the official division of the EU and the UK for regional statistics, visualised on maps, allowing for a more detailed and accurate representation of climate zones at a level that is both informative and accessible for school education. Dividing Europe into these regions, students can understand how

climate types can change, not only across countries, but also within different areas (subnational areas) of the same country, promoting a more comprehensive understanding of climate diversity.
As stated above, the NUTS2 (Nomenclature of Territorial Units for Statistics) regional divisions were used, but not all European countries are included. The regions are parts of the 27 countries that are members of the European Union (EU) (Austria, Belgium, Bulgaria, Croatia, Cyprus, Czechia, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden) and the United Kingdom (UK), which officially from 31 January 2020 is no longer part of EU (*Timeline - The EU-UK Withdrawal Agreement - Consilium*, n.d.). Also, are included the four (4) countries that are part of Schengen Area (European Free Trade Association (EFTA), Iceland, Norway, Liechtenstein and Switzerland. There are included some of the EU candidate countries as Albania, Serbia, Turkey, North Macedonia and Montenegro (*Maps - Eurostat*, n.d.). The image below (Figure 4.6), presents all the regions included in this study for the creation of Europe's climate map, except those in the United Kingdom (UK) (*NUTS-2021-2*, n.d.).

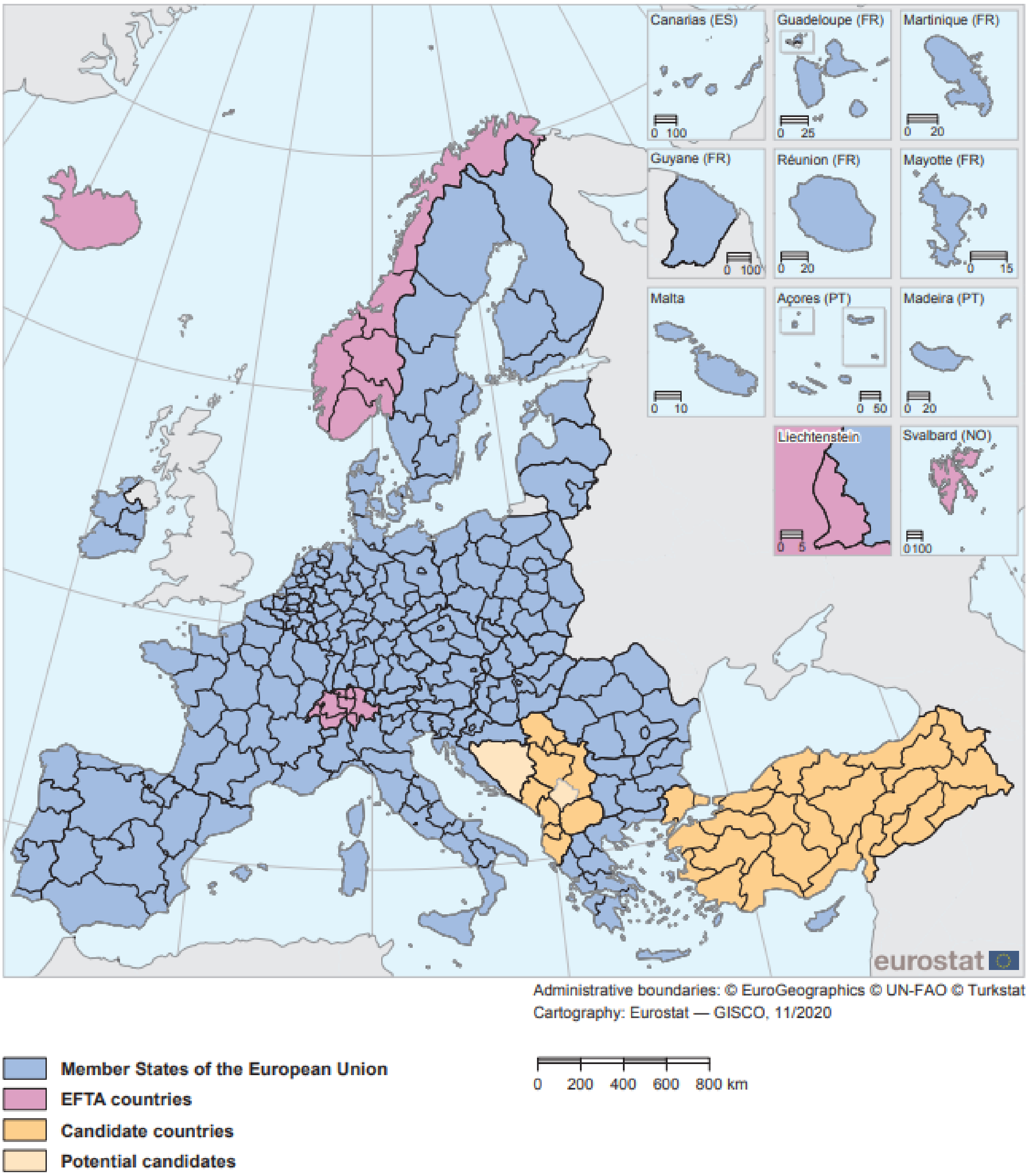


*Figure 4.6: NUTS 2 regions of European Union (EU) according to NUTS 2021, with corresponding statistical regions in EFTA countries, candidate countries and potential candidates.*

### 4.3.3. Assignment Process

The objective was to determine the prevailing climate category for each region based on the Köppen-Geiger classification. However, this was not immediately clear for all regions. It was necessary a comparison of climatic data from Köppen-Geiger maps or data collections from meteorological websites (Beck et al., 2018, 2023; Peel et al., 2007; *World Bank Data | Climate Change Knowledge Portal*, n.d.). The primary sources used were 'koppen.earth' and additional scientific studies referenced in the bibliography to match each area with a single climate category (Beck et al., 2018, 2023; Esri, USGS | ArcGIS, n.d.; Köppen-Geiger Explorer, n.d.). This process was carried out manually, without the use of any automated algorithms. Initially, all available NUTS2 regions were documented in an .xls file (supplementary material for this study). For each region, a dominant climate category (zone) and the corresponding colour were selected based on the student-friendly Köppen-Geiger climate classification created for this purpose. The methodology used to assign each region to a specific category was as follows: if a region fully fell into a specific category, it was directly assigned the corresponding colour and category from the six (6) unified (broad) categories defined. In cases where a region contained more than one of these six (6) categories, the category that covered the largest part of the area was selected based on estimation. Once the file was fully completed, the data was imported into 'Datawrapper'.

#### 4.3.4. Final Map

The final version (Figure 4.7) provides a clear representation of Europe's climate zones using colour coding based on the Köppen-Geiger classification. It is a well-considered synthesis of geographic and climatic data. The visual simplicity of the map makes it accessible to young students, enabling them to easily identify and compare different climate regions across Europe. Each climate zone is assigned a distinct, vivid colour (based on RGB model) that contrasts well with the others, ensuring that the zones are easily identifiable and that boundaries between different climatic regions are clear (*RGB Colour Model | Britannica*, n.d.; Xu et al., 2022). As mentioned in previous chapters this colour selection improves functionality by allowing young students to intuitively distinguish between regions with varying climate characteristics (Bobek & Tversky, 2016; Cromley & Chen, 2023; Understanding How We Learn, n.d.). The tool's customisation options were utilised to adjust the visual settings, such as border clarity, colour contrast, and label placements, optimising the map's readability and making it visually accessible for a school audience. For educational purposes, it was decided not to include a topographic map layer with another tool such as a GIS (Geographic Information System), that would display all regions and country names of Europe in detail. This could cause the static map to become overly complex, making it challenging for students to understand the full picture (Bobek & Tversky, 2016). Thus, a simpler and effective approach was chosen. In nearly every European country, one or more major/ big cities (up to a maximum of three per country) were randomly selected. Labels for these cities were added to the map at their precise geographical locations, marked with black dots (points), and their names were displayed in black text to ensure clarity. To enhance the educational value, a legend was created. It presents the six (6) climate categories (zones), each represented by corresponding colours and symbols (icons) where applicable. This legend helps viewers comprehend the map by linking colours to climate types and serves as a quick reference tool for understanding the spatial distribution of different climate zones across Europe. The recognizable symbols (icons) it includes work as a visual cue to help students quickly identify each climate's key characteristics. Once finalized, the map was exported in high resolution, making it suitable for both digital and print formats, which is especially useful in classrooms for examination on larger screens or printouts.

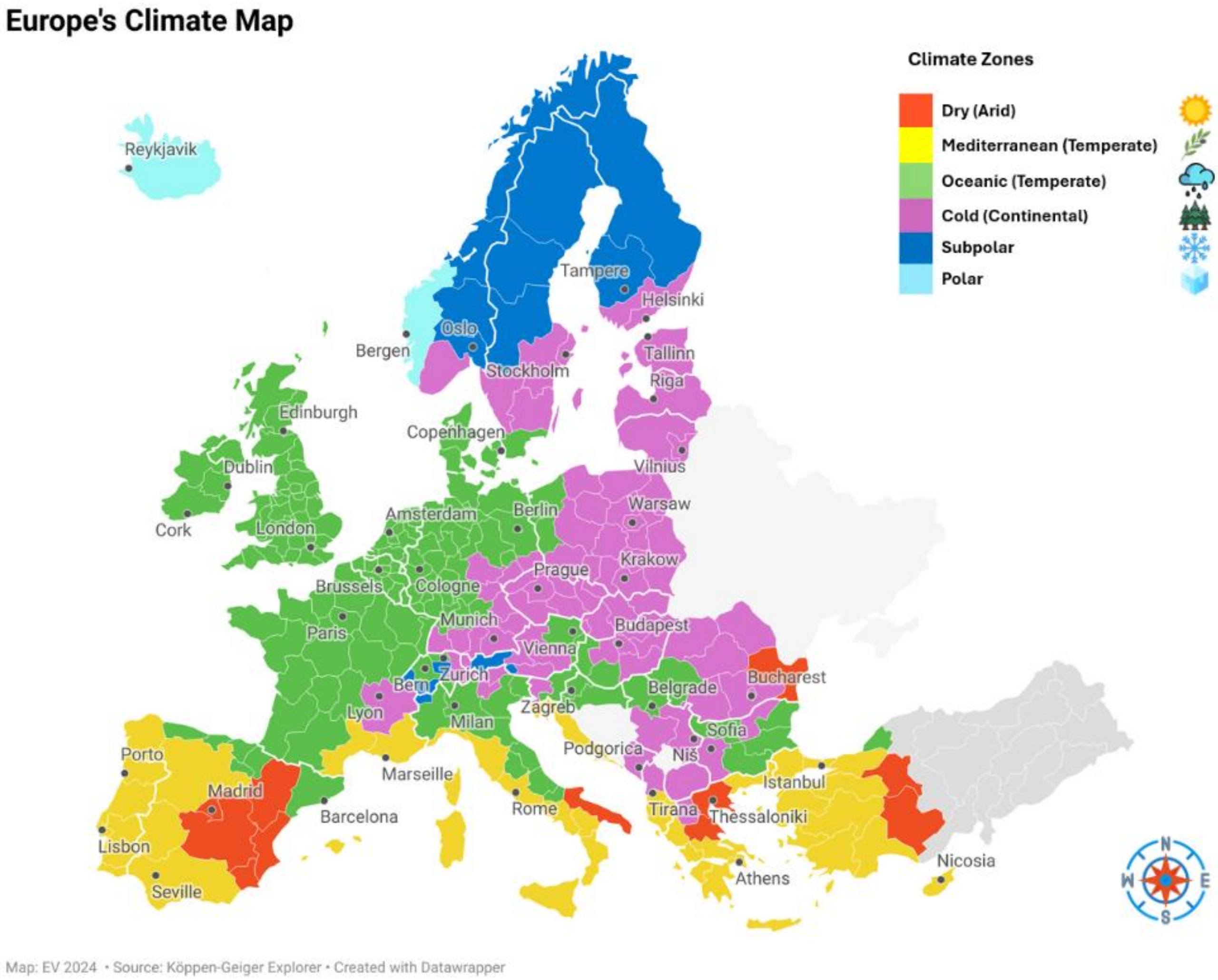


*Figure 4.7: Final Map 'Europe's Climate Map for students'*

### 4.3.5. Map Overview

This climate map of Europe provides a colour-coded system to represent various climate zones according to the student-friendly Köppen-Geiger classification. Upon examining the map, it is observed that:

- **Dry (Arid) – Red**: Limited to some areas in the south, particularly parts of Greece, Italy and Spain. The map displays regions surrounding major cities such as Thessaloniki and Madrid.
- **Mediterranean (Temperate) – Yellow**: Covers southern Europe, including most of Spain, Portugal, southern France, Italy, Greece and parts of the Balkans. The map shows areas with this type of climate around cities like Lisbon, Marseille, Rome, Athens, etc.
- **Oceanic (Temperate) – Green**: Spreads across western Europe, including the British Isles (UK and Ireland), most of France, Belgium, Netherlands, northern Spain, most of Germany and parts of northern Italy. The big cities distinguished in this zone are Dublin, London, Paris, Brussels, Amsterdam, Copenhagen, Milan, etc.
- **Cold (Continental) – Purple (Magenta)**: Found in central and eastern Europe, stretching through parts of Scandinavia, the Baltic States (Estonia, Latvia, Lithuania), Austria, Czech Republic, Poland, and into the interior of the continent. This category includes areas that are close to Munich, Vienna, Budapest, Bucharest, Sofia, Riga, Warsaw, etc.

- **Subpolar – Blue**: Visible in northern Scandinavia, mainly in Sweden, Norway and Finland. Also, it is found in some areas of Austria and Switzerland in central Europe (European Alps). Through the map, the cities like Tampere and Oslo appear to have a subpolar climate.
- **Polar – Light Blue (Cyan)**: Only depicted in the far north of Europe, such as Iceland, and parts of Scandinavia as western Norway. The map highlights cities with this type of climate, such as Bergen and Reykjavik.

Aside from these main observations, the student-friendly map helps students recognize that even within a single country, there can be significant climate variations. For instance, in France, which is primarily classified as having an Oceanic climate, the map shows distinct variations. While most of northern and western France, including cities like Paris, experiences an Oceanic (Temperate) climate, southern France near the Mediterranean coast, including cities like Marseille, has a Mediterranean (Temperate) climate. Moreover, the map allows the viewers to compare climates across countries and observe similarities between geographically distant regions. According to the map, Marseille, located in southern France, shares a Mediterranean climate with cities such as Rome in Italy and Athens in Greece. Despite being in different countries, these similarity of climate highlights how specific regions in Europe share similar climates regardless of country borders, offering a broader perspective on European climates. The map shows that Europe's climate changes gradually from north to south and from west to east. In the north, places like Iceland, Norway, Sweden, and Finland have very cold Subpolar and Polar climates. Moving further south, the climate becomes less cold, changing to Cold (Continental) in central Europe and eventually to Oceanic and Mediterranean climates in the south. This pattern presents the latitude effect as regions closer to the Arctic Circle are colder and have harsher weather, while regions further south, near the Mediterranean Sea, are warmer and have milder conditions.

#### 4.3.6. Advantages of the Map

The 'Europe's Climate Map for students' offers numerous advantages as an educational tool, such as:

- **Easy to Understand**: The use of bright colours, simple classifications, and intuitive symbols (icons) makes the map visually appealing and easy for students to understand (Cromley & Chen, 2023; Raiyn, 2016; Xu et al., 2022). Clear colour differences for each climate zone help reduce cognitive load, allowing students to easily distinguish regions without needing detailed explanations (Bobek & Tversky, 2016; Clark et al., 2011). Each climate zone is colour-coded and accompanied by a specific icon that visually represents its characteristics. This dual use of colours and symbols makes it easier for students to remember and recognise different climates, enhancing their ability to process and retain information (Cromley & Chen, 2023; Understanding How We Learn, n.d.; Xu et al., 2022).
- **Educational Value**: The map serves as a valuable educational tool that goes beyond simply presenting data. It introduces students to the concept of regional diversity within Europe. They could understand the idea that Europe is not a homogenous climate entirely, but a continent with various climatic regions, each with its unique characteristics. This understanding can lead to a deeper critical thinking by prompting students to ask questions about the climate patterns they see. For example, 'Why do most regions of southern Europe have mediterranean climate, while western Europe has oceanic climate?' or 'Why the majority of regions in central Europe classified as cold (continental) and how does that differ from the oceanic climate in western Europe?' Such questions encourage students to think about how geographical location and natural features influence climate. Additionally, another important educational benefit of the map is that it helps students develop map-reading skills. Students can learn to find regions,

understand symbols, read the legend, and draw conclusions from visual information. This map is an easy introduction to these skills, which will be valuable in future studies involving more complex geographic or data-based maps. Finally, the map's student-friendly (simplified/ modified) design helps young learners make it easier to remember all the important information for their age without unnecessary details (Clark et al., 2011; Mestre & Ross, 2011; Raiyn, 2016). This method builds a strong foundational understanding of climate that can be expanded upon in later educational stages.

- **Supports the Educators**: The simplified classification allows educators to easily convey fundamental climate concepts and regional differences in Europe. The map's design supports various teaching methods, making it a flexible classroom resource. Teachers can use it as a visual aid in lectures or discussions, allowing students to follow along visually as they explore different climate zones (Bobek & Tversky, 2016; Clark et al., 2011; Raiyn, 2016). This flexibility allows teachers to adapt the map to different learning environments, whether in traditional lessons, group work, or even independent study. Educators can use the map to ask questions such as mentioned above (Educational Value), that increase and improve critical thinking of students.

## 5. Climate Risks

Europe faces a range of climate risks, which are becoming increasingly severe due to the effects of global climate change. Global warming and climate change are causing a shift in climate zones, making all regions warmer and drier (*Consequences of Climate Change - European Commission*, n.d.). Due to climate change is causing a rise in temperature and alterations in weather patterns. These changes can occur naturally, but are now more driven by human activities. Summers in Europe are increasingly hotter, heavy rainfall and flooding are becoming more frequent and large areas are burnt by wildfires annually (European State of the Climate 2023, n.d.). The key physical events that are seen in Europe are:

- **Heatwaves (Extreme Heat):** Prolonged periods of extremely high temperatures, often lasting several days. Almost all over Europe, they are becoming more frequent and intense, especially during the summer. These extreme heat events significantly impact ecosystems, causing serious health problems (heat-related illnesses), water shortages as resources dry up quickly, power shortages and agricultural losses (*Heatwaves | Copernicus*, n.d.).
- **Flooding:** It happens when storms and intense rainfall (heavy precipitation) or snowmelt causes rivers, lakes, or coastal areas to exceed their capacity and overflow. This is often made worse by dry soils that are unable to absorb water quickly, especially in places with poor drainage systems. In Europe, the severe storms are growing in intensity due to changes in atmospheric conditions. Flash/ sudden flooding can lead to serious problems as property damage, transportation disruptions and harm to wildlife and vegetation. Notable examples include Storm 'Hans' in Norway and Sweden, Storm 'Minerva' in Italy, and Storm 'Daniel' in Greece, all of which occurred in 2023 and caused severe flooding with extensive damage to the affected regions (*Flooding | Copernicus*, n.d.).
- **Drought:** Widespread and prolonged drought are caused by high temperatures with exceptional heatwaves and limited rainfall (lack of precipitation). These conditions result in extremely dry soil and put significant strain on water resources, affecting both agriculture and urban water supplies. Droughts can also threaten wildlife and the economy of a region, disrupting food production and energy generation. In recent years, many areas in countries such as Spain, Portugal, France, Hungary, and Romania have faced a heightened risk of drought from April to September (Wens, 2023).

- **Wildfires:** They are large, uncontrolled fires that spread rapidly through forests, grasslands and other areas. High temperatures, dry conditions and winds, especially in the summer months, have led to numerous wildfires, most of them in southern Europe (e.g., Greece, Portugal, Spain, Italy). Fires often threaten lives impacting ecosystems and air quality, destroy homes, and cause economic damage to tourism and agriculture. In recent years, Europe has experienced an increase in the frequency, size, and duration of wildfires, resulting in a longer fire season (*Wildfires | Copernicus*, n.d.).
- **Melting Glaciers**: Glaciers are large ice formations found in polar (arctic) areas and mountain ranges, like central Europe (European Alps), Scandinavia and Iceland. All European regions have experienced a significant net loss of glacier ice each year. As temperatures increase, vast amounts of water stored in glaciers and ice sheets melt, contributing to rising sea levels, which can cause coastal flooding (*Glaciers | Copernicus*, n.d.).

As noted in the discussion of the map in the previous chapter, it was essential to minimize the choices of climate risks reducing cognitive load for educational purposes (Mestre & Ross, 2011). Consequently, five (5) key events were selected. This approach ensured that the information presented in the infographic remained accessible and straightforward for young learners (Bobek & Tversky, 2016; Clark et al., 2011; Martinelli & Raykov, 2021). The student-friendly infographic image below, provides a visual summary of the specific climate risks that was explained previously and linking them with each climate zone according to the ’Europe's Climate Map for students’ (Figure 4.7) This could help young students visualise how these risks are distributed across Europe and understand the regional impacts of these risks while the text elaborates on the causes, effects, and consequences of these events.
The infographic includes symbols (icons), that are highly effective in communicating complex climate risks in a simple and understandable way. Each symbol has been carefully chosen to represent a physical risk of climate zones. These visual elements are clear, engaging, and easy to understand, making them especially suitable for young learners (Bobek & Tversky, 2016; Clark et al., 2011; Xu et al., 2022). Each climate zone is illustrated with its own set of icons that represent the unique risks associated with that zone. Specifically, on the right side of the infographic, there is a section that presents the types of climate risks. Each risk is represented by a specific symbol (icon):

- ‘Thermometer’ represents heatwaves, highlighting the extreme and rising temperatures. The design focuses on a universally recognised tool used to measure temperature, making it an intuitive symbol for heat-related risks. The use of red, a colour often associated with heat and danger, enhances its visual impact and draws immediate attention
- ‘House and tree submerged in water’ symbolises flooding. Especially by showing a house-a universal symbol of safety and stability- partially submerged, the icon emphasises how flooding disrupts normal life, damages property, and poses risks to human safety. The inclusion of a tree subtly hints at the environmental impact, as floods not only affect human infrastructure but also disrupt natural ecosystems.
- ‘Water tap dripping on dry soil’ communicates the concept of drought by illustrating limited water availability and dry conditions.
- ‘Flame’ represents the large and uncontrolled wildfires. Its minimalistic design makes it universally recognisable as a symbol of fire.
- ‘Iceberg’ stands for melting glaciers event. A simple and easily recognisable symbol that presents the fragility of frozen environments.

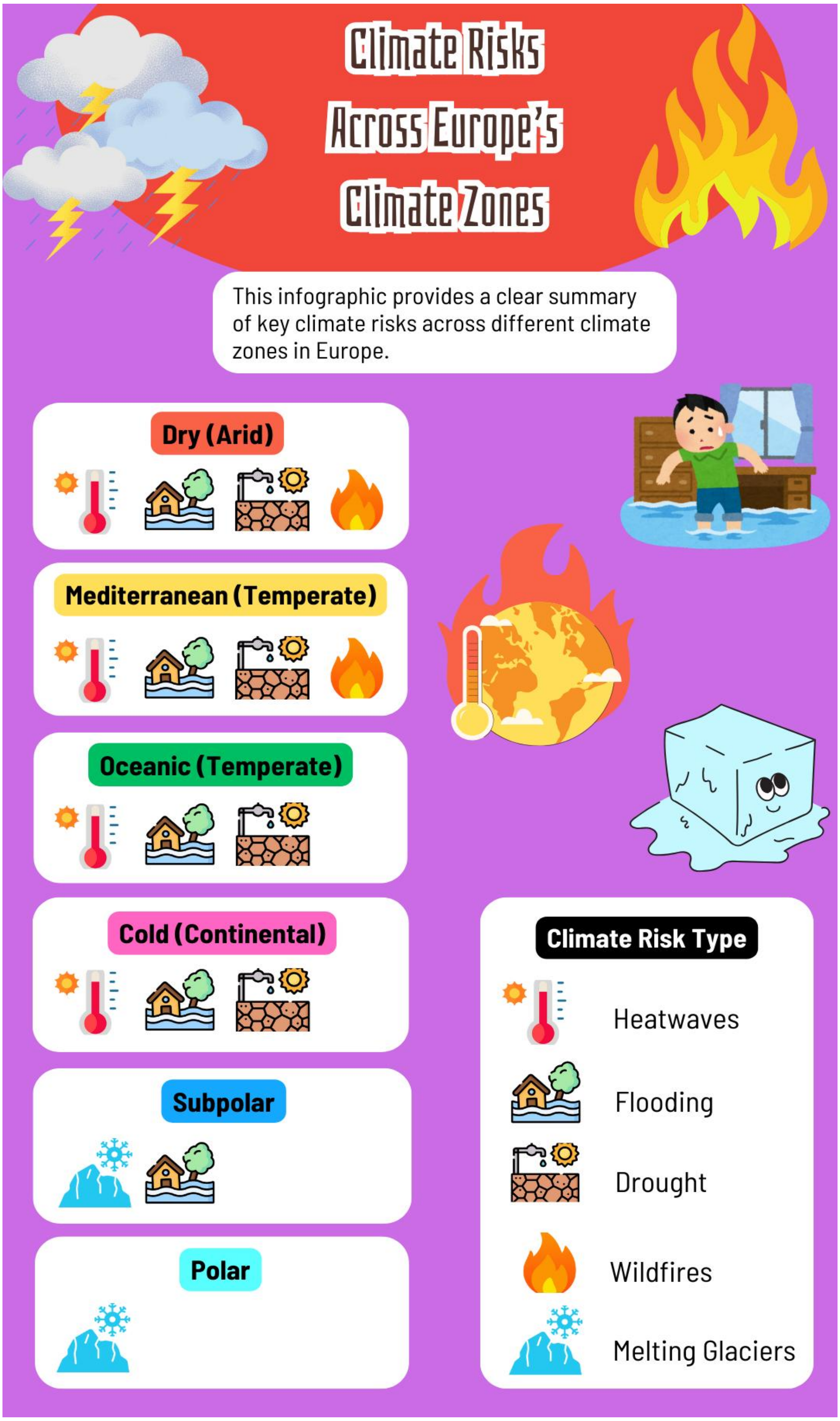


*Figure 5.1: Student-friendly infographic 'Climate Risks Across Europe's Climate Zones'*

On the left side of the infographic, there are six different sections, each representing a specific climate zone and featuring one or more symbols assigned to the corresponding climate risks. The assignment of each climate risk to its corresponding section was determined based on the geographical location of the areas influenced by each climate zone. This classification was based on reports from trusted European Union (EU) sources, like Copernicus and the European Environmental Agency (EEA), to confirm that that these phenomena are observed in the regions associated with each specific climate type (Eea, n.d.; European State of the Climate 2023, n.d.; EUROPEAN STATE OF THE CLIMATE SUMMARY 2021, n.d.; EUROPEAN STATE OF THE CLIMATE SUMMARY 2022, n.d.; STATE OF THE CLIMATE, n.d.; *Urban Adaptation in Europe: How Cities and Towns Respond to Climate Change*, n.d.). The 'Dry (Arid)' zone includes symbols representing heatwaves, flooding, drought and wildfires reflecting the harsh and dry conditions typical of this climate type. These same symbols are repeated in the 'Mediterranean (Temperate)' zone, as it shares similar risks, particularly during its hot and dry summer months. The 'Oceanic (Temperate)' while also prone to heatwaves, flooding and drought, this section does not include the symbol for wildfires, suggesting that these are a less prominent concern in regions with Oceanic climate compared to areas with Dry (Arid) and Mediterranean climates. For the 'Cold (Continental)' zone, the icons are the same with 'Oceanic (Temperate)' climate zone, wildfires are not included as a major risk. The 'Subpolar' zone focuses on symbols for flooding and melting glaciers, emphasising the impact of snowmelt and rising temperatures. Finally, the 'Polar' zone features the 'Iceberg' icon exclusively, representing the risk of melting glaciers, a key concern in the regions that are affected by this climate.

The infographic was created using 'Canva', a free online graphic design tool. (Canva: Visual Suite for Everyone, n.d.). The symbols used in this infographic were carefully selected from a copyright-free source (Flaticon: Free Icons and Stickers, n.d.). The colours used for each zone match those in the map (Figure 4.7), ensuring consistency and aiding visual recognition. Bright colours and clearly defined labels enhance clarity and make the infographic visually appealing. Designed with educational purposes in mind, the infographic simplifies complex information about climate risks into an engaging and accessible format (Clark et al., 2011; Cromley & Chen, 2023; Mestre & Ross, 2011; Xu et al., 2022). Its playful and friendly elements, make the content approachable for school students while still addressing critical topics. This thoughtful design strikes a balance between being informative and age-appropriate, effectively communicating important climate concepts to young learners (Bobek & Tversky, 2016; Clark et al., 2011; Martinelli & Raykov, 2021).

This infographic was created as additional content to accompany the 'Europe's climate map for students' (Figure 4.7), helping young learners understand and connect these risks to the climate zones they will study through the map.

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