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Climate Change and Cities of Lithuania: Threats, Problems and Prerequisites for Solution

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Abstract: The emerging threats of climate change and their impacts on cities and residents are increasingly highlighting the need to assess whether countries are adequately prepared for the potential consequences of this process. While many international agreements on climate change, sustainable development and environmental protection have been adopted, countries often face various local obstacles that hinder their implementation. To address these issues, this paper reviews the climate change projections, emerging threats and hazards in Lithuania and their potential impacts on the country's cities and highlights the main challenges in preparing for these growing threats. This article presents an evaluation of the climate change forecasts and past climate events in three selected Lithuanian cities—Vilnius, Kaunas and Klaipėda. The study includes a diagnostic assessment of the climate changes since 1961 and climate change forecasts up to 2100, based on the RCP4.5 and RCP8.5 scenarios, using regional and global climate models. It identifies the impacts of potential climate change consequences on cities, forming the basis for the evaluation of the urban situation in the country. The urban situation is assessed in terms of legislation, urban development, environmental requirements and the development of safety infrastructure. Based on the evaluation of urban development, preliminary proposals are provided for the creation of a resilient living environment. One of the key proposals in shaping the living environment—which could be particularly significant in adapting to emerging threats—is the complex formation of new, sustainable urban structures that take into account the social, ecological and economic factors of climate change and other rising threats.

Keywords: climate change; heatwaves; storms; floods; war dangers; sustainable urban planning of towns; environmental protection

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1. Introduction

Global climate change and its devastating consequences have been discussed for quite some time [1,2]. We continually read and hear reports about alarming heatwaves, floods, hurricanes, storms, fires and other large-scale disasters with massive numbers of casualties [3,4]. Recently, additional threats have contributed directly and indirectly to these dangers, including pandemics, the risks of war, radiation, air pollution and other factors, which could lead to a global ecological catastrophe [5,6].

To mitigate the threatening processes of global climate change, global warming and other negative impacts, several important international documents have been issued. These include the Kyoto Protocol, signed in 1998 [7]; the Paris Agreement in 2015 [8]; and several relevant European Union decisions, such as the 2011 EU Communication on the European Resource Efficiency Plan [9]; the 2013 decision on the EU's Environmental Action Programme up to 2020, 'Living well within the limits of our planet' [10]; and the EU Communication titled 'Managing climate risks: protecting people and prosperity' in 2024 [11]. In 2020, the European Union adopted its most ambitious set of policy initiatives aimed at making Europe the world's first climate-neutral continent by 2050—the European Green Deal strategy [12]—followed by a series of related documents for its implementation.

Based on these international legal frameworks, individual countries have supplemented their national legal bases. Specifically, in Lithuania, the National Climate Change Management Policy Strategy was approved by the Seimas (Parliament of the Republic of Lithuania) in 2012 [13], and the National Climate Change Management Agenda was adopted in 2021 [14]. There have also been updated documents such as the Law on Climate Change Management [15] and the Law on Crisis Management and Civil Protection [16], among others.

However, both international and national legal frameworks are not being adequately implemented across all EU countries, and they still do not ensure the necessary changes to combat the irreversible global processes of climate change; moreover, the required preparation for potential threats is lacking. According to the statistics from sustainable development reports, the countries making the greatest efforts to achieve their sustainable development goals are Finland, Sweden, Denmark, Austria, Norway, Germany, Switzerland, Slovenia, Belgium and others, while Cyprus, Romania, Bulgaria, Greece and Lithuania are among those making the smallest efforts [17].

The ongoing climate change and possible future scenarios are being evaluated by many researchers and responsible institutions worldwide (Intergovernmental Panel on Climate Change—IPCC [18], Copernicus Climate Change Service [19], World Meteorological Organisation—WMO [20]). Studies indicate potential changes in air temperatures and the corresponding consequences of this process, highlighting the necessity to assess these changes in detail. In response to the impacts of climate change on natural processes, emerging issues include rising global sea levels [21,22], intensifying heatwaves [23,24], increasing heavy rainfall and subsequent river flooding [25,26]. Additionally, recent years have seen a focus on equally pressing issues such as pandemics and escalating war threats [6,27].

To adapt to these emerging threats and avoid their negative consequences, the effectiveness and efficiency of national policies are being evaluated [28,29]. Increasingly important are studies on the impacts of human activities on the environment and the potential to become climate-neutral [30,31].

When reviewing global threat assessments and studies, it is clear that climate change processes are occurring, raising an increasing number of questions that need to be addressed at both the international and national levels (heat islands, floods, fires, urban environment resilience). Despite this, in many countries, pragmatic territorial development continues, encroaching on new agricultural areas, ignoring the importance of environmental requirements and delaying proper assessments of potential climate change threats [32]. Additionally, while countries declare sustainable development goals or claim to strive for climate neutrality, statistics indicate that, in many areas, their actions are contrary to these goals. This highlights critical gaps in national governance and a lack of control, where international commitments are only partially incorporated into national legal systems and inadequately aligned with the actions of local governments [33].

Based on the conducted studies, it can be stated that the evaluation of the necessary sustainable land use and adaptation measures regarding the consequences of climate change at the national level in individual countries has not yet been fully completed. International organizations assess only certain territorial and environmental data indicators, providing general recommendations, without a detailed evaluation of the legal gaps or other factors at the national level that prevent the achievement of the sustainable development goals [34]. A more detailed evaluation of sustainable land use has been carried out by individual authors in some countries [35,36]. However, there is still no comprehensive solution to address the problems arising in a broader international context, apart from strategic provisions and recommendations [37].

Considering the need to further develop these studies, it is necessary to conduct a more detailed assessment of each country's climate change situation and emerging threats, as well as to analyze the implementation of measures aimed at sustainable land use and adaptation to climate change, identifying the main institutional and legal gaps that should be addressed as soon as possible.

This article aims to review the climate change issues that have become evident in the Lithuanian context and new, emerging threats experienced in recent times—war, radiation, pandemics—and their impacts on the country's cities, living environment and people. It also seeks to assess the country's preparedness to combat these threats and provide suggestions and assumptions to mitigate their impacts.

Such studies would complement the national studies conducted by individual countries and would be relevant in addressing the challenges of adapting to climate change and preparing to overcome its potential threats in Eastern Europe and the Baltic region. Considering the research carried out by many authors in the discussed field, this article aims to draw more attention to the importance of urban governance and the shortcomings of national and local government actions, which often lead to unacceptable urban development decisions. This research seeks to emphasize the necessity of strengthening urban governance, which is relevant to many countries in the pursuit of creating a sustainable living environment

2. Materials and Methods

To achieve the abovementioned goals, this article first reviews the global climate change situation (Section 3.1) and presents detailed forecasts for the case of Lithuania (Section 3.2). The extreme events caused by climate change in Lithuania and their impacts on the living environment are further evaluated (Section 3.3). Considering the significance and relevance of these factors, the country's urban environment—which is directly affected by the consequences of climate change—is reviewed, with its development being one of the essential issues in adapting to climate change (Section 3.4). Based on this research, the Discussion provides assumptions for potential urban measures aimed at sustainable development and effective adaptation to climate change (Section 4).

This article offers an overview of the global and Baltic Sea region's climate change, analyzing research conducted by international organizations and presenting climate change future scenarios. Based on the examined forecast scenarios, this article presents a diagnostic assessment of climate change, identifying specific forecasts of various climate indicators for Lithuanian cities. The forecasts for various climate indicators (heatwaves, hot days, wind, heavy rainfall, etc.) are calculated for three Lithuanian cities: Klaipėda (representing the coastal and Western Lithuania region), Kaunas (representing Central Lithuania) and Vilnius (representing Eastern Lithuania). For the diagnostic assessment of climate change in Lithuania, two standard climate normals (SCN) are compared, 1991–2020 and 1961–1990, based on information provided by the Lithuanian Hydrometeorological Service. The climate projections for Lithuania up to 2100 are based on data from the Coupled Model Intercomparison Project Phase 5 (CMIP5) and Representative Concentration Pathway scenarios RCP4.5 and RCP8.5 [38,39]. The climate projections are calculated from a combination of two global climate models or GCMs (namely the Irish Centre for High-End Computing (ICHE), https://www.ichec.ie/, and Max Planck Institute (MPI), https://mpimet.mpg.de/en/science/models/mpi-esm (accessed on 27 January 2024)) and two regional climate models or RCMs (the Rossby Centre of SMHI (RCA), https://www.smhi.se/en/research/research-departments/climate-research-at-the-rossby-centre/rossby-centre-regional-atmospheric-model-rca4-1.16562, and the CCLM, https://www.cmcc.it/models/cosmo-clm-climate-limited-area-modelling-community (accessed on 27 January 2024)).

For the assessment of extreme phenomena, both qualitative and quantitative data analysis methods are used. This analysis covers a review of data sources on natural disasters—heatwaves, hot days, heavy rainfall and windy days—the data accumulated during the instrumental meteorological measurement period and the assessment of their impacts and the resulting damage to the living environment. The data from the Lithuanian Hydrometeorological Service (LHMS), which have been collected since 1961, are used for the analysis of climatic phenomena [40]. Lithuanian insurance data [41] are used to assess the extent of the damage caused by these events. The provided data are used in the study along with the data selected for the studied cities—Vilnius, Kaunas and Klaipėda. The data are systematized, and tables and charts are presented. Based on the systematized data, the frequency and nature of the natural disasters are determined.

The urban assessment is conducted in the broader context of the entire country. In assessing the urban development of the country's cities, the urbanization trends, the impact of new construction on the natural environment and cities' preparedness for the consequences of climate change, war and pandemic threats are analyzed. This study examines the legal acts regulating spatial planning, as well as the master plans prepared by all municipalities in the country for the period from 2005 to 2023 [42]. The results of the study are presented in tables and in a prepared land use map considering the solutions of master plans. When evaluating the justification for development areas and their relation to emerging threats, the extent of development areas in flood-risk zones is determined, with data presented in tables. Information from statistical databases and geoinformation data from spatial planning projects are also used in this study: the registry of spatial planning documents—the master plans of municipalities and special plans for protected areas (Construction Sector Development Agency, Ministry of Environment), the protected areas cadaster, flood risk areas, natural framework areas (Environmental Protection Agency) [42,43] and the shelter and cover database (Fire and Rescue Department under the Ministry of the Interior) [44]. Geoinformation system analysis methods using the ArcGIS software (version ArcMAP 10.8.1, ESRI, Redlands, CA, USA) are applied for data analysis and evaluation.

3. Results

3.1. Global Climate Change

Data on changes in the atmosphere, oceans, cryosphere and biosphere provide undeniable evidence of global warming. Over the past few decades, key climate system indicators have consistently reached record-high values and have changed at unprecedented rates over at least the last 2000 years. Human activities, primarily greenhouse gas (GHG) emissions, are unequivocally responsible for global warming (Figure 1). The global emissions of greenhouse gases continue to rise due to the ongoing reliance on fossil fuels for energy production, unsustainable energy consumption in households and industry, land use changes and a consumer-driven lifestyle [18,45].

The year 2023 was the warmest year globally since the start of instrumental meteorological measurements in 1850. The average global surface temperature was 14.98 °C, exceeding the 1850–1900 mean of 13.5 °C by 1.48 °C. The temperature rise may have been amplified by the abrupt transition from La Niña to El Niño in 2023 [19]. Based on six datasets, the average global temperature over the past decade (2014–2023) was 1.20 ± 0.12 °C higher than the 1850–1900 mean, reaching 14.7 °C, accounting for the uncertainty. Since the 1980s, each decade has been warmer than the previous one [20]. The average temperature rise per decade from the mid-twentieth century has been 0.2 °C overall, 0.3 °C on land and approximately half of this value over non-freezing ocean and sea areas. Overall, since 1850, the average global temperature has risen by about 1.2–2.2 °C in Europe and 3 °C in the Arctic region [19,46].

The 2023 UN Climate Change Conference (COP28) highlighted the inadequacy of the current mitigation efforts to meet the targets of the Paris Climate Agreement. The average global temperature is already 1.2 °C above pre-industrial levels, indicating that the current national climate mitigation plans are evidently insufficient. Even if these plans were implemented, the global temperatures would still be at least 2.4–2.6 °C higher than the pre-industrial levels by the end of the twenty-first century (the Paris Climate Agreement sets a warming target of 1.5–2.0 °C).

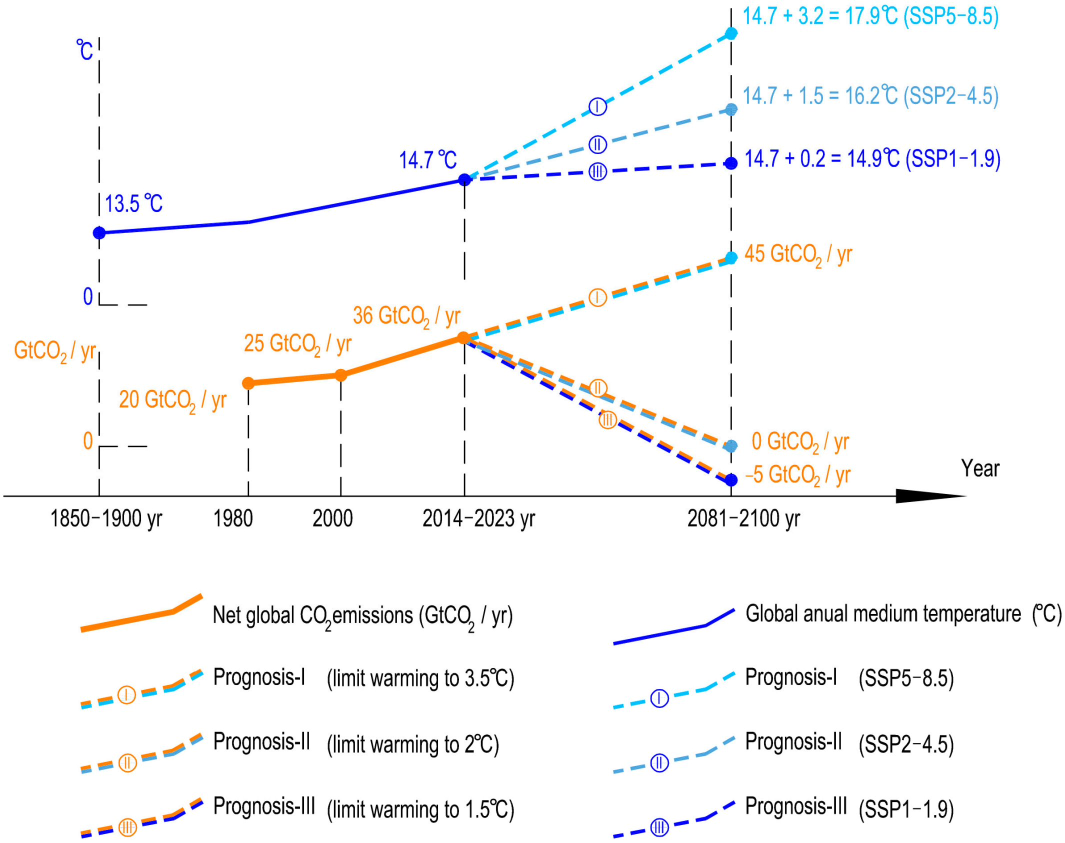


Figure 1. CO_2 emissions from fossil fuel combustion (Gt per year) and average annual global temperature anomalies from the 1850–1900 mean (based on six datasets) reflect past trends and benchmark forecasts. Source: World Meteorological Organisation (WMO) Greenhouse Gas Bulletin No. 19 (2023) [20]; State of the Global Climate (2023, 2024) https://wmo.int/publication-series/state-of-global-climate (accessed on 27 January 2024); Intergovernmental Panel on Climate Change (2023) https://www.ipcc.ch/report/ar6/syr/figures/figure-spm-5 (accessed on 27 January 2024) (compiled by the authors).

The COP28 documents also emphasize the importance of addressing the interplay between climate change and human health and well-being within the context of the United Nations Framework Convention on Climate Change (UNFCCC) and the Paris Agreement [7,8,47]. National climate mitigation and adaptation plans must be adequate for the current situation, more effective and inclusive, realistically implementable and cover comprehensive climate monitoring and evaluation indicators [47]. Moreover, the IPCC concludes that, even if the temperature rise slows over time and the Paris Agreement goals are met, the risks associated with climate change will not be reduced due to the complex feedback mechanisms in the climate system and its inertia. This, in turn, will inevitably lead to significant economic and non-economic losses, necessitating an increased focus on effective climate mitigation and adaptation measures [46,48].

Global warming is expected to continue to intensify in the near future (by 2040), likely reaching or exceeding the 1.5 °C limit to pre-industrial levels that was agreed in the Paris Agreement, mainly due to increasing GHG emissions under nearly all considered and modeled scenarios (since pre-industrial time the average global temperature has already risen by about 1.2 °C) [49]. In the IPCC AR6, the terminology SSPx-y is used, where 'SSPx' refers to the Shared Socio-economic Pathway or 'SSP' describing the socio-economic trends underlying the scenario, and 'y' refers to the approximate level of radiative forcing (W/m^2) resulting from the scenario in 2100. Evaluating the climate response to SSP scenarios, the most likely estimate for warming from 2014–2023 to 2081–2100 under the low GHG emissions scenario (SSP1–1.9) is 0.2 °C, under the intermediate GHG emissions scenario (SSP2–4.5), it is up to 1.5 °C, and, under the high GHG emissions scenario (SSP5–8.5), it is 3.2 °C [46].

The projected scenarios indicate that, without reductions in GHG emissions and the consideration of their impacts on climate change, the Earth faces a high risk of severe consequences that could lead to catastrophic outcomes. Only by reducing these GHG emissions can the climate change process be mitigated. In this case, there would still be opportunities to adapt to climate change and avoid significant negative impacts.

3.2. Climate Change in the Baltic Sea Region and Lithuania

The Baltic Sea region is characterized by highly contrasting weather conditions due to its geographical location: the region is situated in the mid-latitudes of the Northern Hemisphere (extra-tropical zones), where Arctic, polar (maritime and continental) and even tropical air masses converge. The circulation of cyclonic and anticyclonic vortices is influenced by several large-scale atmospheric pressure systems: the Icelandic Low (a climatic cyclone center in the North Atlantic), the Azores High (a climatic anticyclone center) and a seasonally varying pressure system over Eurasia (high pressure in winter and low pressure in summer). Westerly transport predominates throughout the troposphere; occasionally, blocking anticyclones form over Scandinavia and the Kola Peninsula, impeding westerly transport.

One of the most informative indicators of climate change in the Baltic region is the variation in sea ice cover in the Baltic Sea. Over the past 100 years, the ice cover has been decreasing by 3400 km^2 or by 2% per decade, and, in the last 30 years, warmer winters with ice covering less than 20% of the Baltic Sea have increasingly occurred [50–53]. The sea level is also a significant indicator of long-term climate changes. Due to the combined effects of crustal deformation and volumetric sea level changes, the relative sea level (RSL) is falling in the northern Baltic Sea and rising in the southern part. Along the Lithuanian coast, the long-term rising trend in the RSL averages 1.3–2.9 mm per year, with a rise of approximately 15–20 cm since the late nineteenth century, and, since 1993, by 4–5 mm per year [51,54–56]. Based on satellite altimetry and coastal measurements, various authors estimate that the absolute sea level in the Baltic Sea has risen by an average of 1.3–2.1 mm per year over the past 130 years, and, since 1993, by 2.4–6.5 mm per year [51,56,57]. The global ocean sea level has risen by an average of 3.3 mm per year since 1993 [46].

Global warming leads to a rise in the global sea level, primarily due to land ice melt and the thermal expansion of the world's oceans (volume increase). According to moderate scenarios (e.g., SRES A1B, RCP4.5, SSP2–4.5), the global sea level is projected to rise by 0.70 $\pm$ 0.30 meters by the end of the twenty-first century, while high-end (pessimistic) scenarios such as RCP8.5 suggest a rise of up to 1.1 meters. Considering local factors, the average absolute rise in the Baltic Sea level is expected to be 80% of the global average. Along the Lithuanian coast, the relative sea level is projected to rise by about 0.20–0.30 meters by the end of the twenty-first century under moderate scenarios (e.g., RCP4.5) and by up to 0.35–0.60 meters under high-end scenarios (e.g., RCP8.5) [38,51,56].

These projections are based on various climate change scenarios, atmospheric general circulation models (with enhanced spatial resolutions) and output data from various regional climate models (RCMs). On this basis, it is projected that, by the end of the twenty-first century, the air temperatures in the Baltic region will rise to more than the global average due to a pronounced temperature increase during the winter season. It is expected that, by the end of the twenty-first century, the winter temperatures will be 3–9 °C higher and the summer temperatures will be 1.5–6.0 °C higher compared to the end of the twentieth century. A warmer atmosphere may retain more moisture, leading to a modeled response to rising global temperatures—the intensification of the hydrological cycle. It is projected that the annual precipitation will increase across the entire Baltic Sea Basin, with a greater increase in winter than in summer—20–30% and 10–15%, respectively [51].

Additionally, an increase in the frequency of short-term (1–3 days in duration) intense precipitation events is expected throughout the year [51,58].

Extreme weather phenomena are highly significant for many areas of human activity. Intense and heavy precipitation leads to river floods and urban inundation, as well as soil erosion. Droughts and heatwaves have reduced the total amount of living biomass in Lithuania's forests, led to the proliferation of tree pests and diminished the greenhouse gas absorption potential of biomass [59,60]. This necessitates greater attention to this aspect of anthropogenic climate change. In many Baltic region countries, an analysis of the extreme temperature events since the mid-twentieth century has revealed statistically significant changes: an increase in the number of days with maximum temperatures exceeding 25 or 30 °C, an increase in the number of tropical nights (minimum night-time temperatures $\geq$ 20 °C) and a decrease in the number of ice days (maximum daily temperatures below 0 °C) and frost days (minimum daily temperatures ≤ -20 or ≤ -25 °C) per year [51,61,62].

In Lithuania, the following changes in these climate indicators can be noted. The average annual temperature based on the 1991–2020 climate normals (CN) in Lithuania was 7.4 °C, which was 1.2 °C higher than in the previous period (1961–1990 CN). The most significant increases in the temperature in Lithuania were observed from January to April and from July to August (1.4–2.2 °C). In other months, the temperature during the analyzed period increased by 1.3–0.1 °C (with the smallest changes occurring in October). The average annual precipitation increased by only 3%, but the changes in the precipitation amounts for individual months were uneven. For example, in April, September and November, the amount of precipitation decreased by an average of 12%, while, in January and February, it increased by 26% and 43%, respectively. It was also found that, in Lithuania, there was a 12% increase in heavy precipitation events ($\geq$20 mm per day), a 32% increase in the number of hot days (maximum daily temperature $\geq$ 25 °C), a 25% average decrease in the number of days with snow cover, a 16-day reduction in the length of the meteorological winter and a 13-day increase in the length of the meteorological summer.

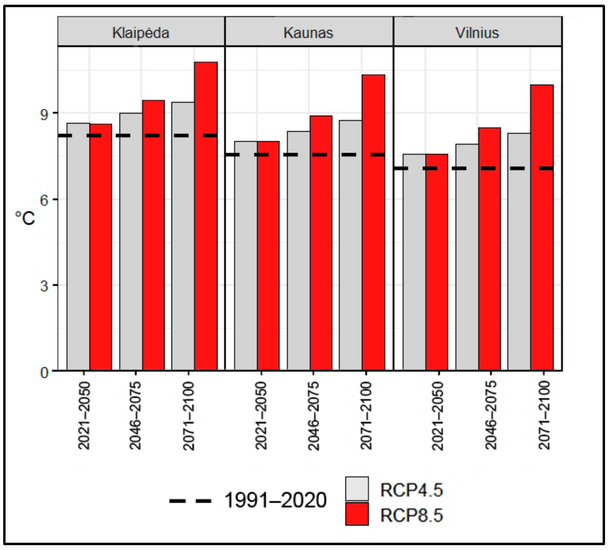
Changes in climate indicators—such as the temperature, precipitation amounts and duration of heatwaves—have a significant impact on urban functionality, the quality of the living environment and energy consumption [49,63]. According to climate projections, this impact will intensify, making it crucial to consider when shaping the urban environment. To assess the impact of climate indicators on the urban environment, this article includes an analysis of climate indicator projections for the three largest cities in Lithuania, representing the three main climatic regions of the country: Klaipėda (coastal and Western Lithuania region), Kaunas (Central Lithuania region) and Vilnius (Eastern Lithuania region) (Figure 2). For the analysis of the urban climate situation, the average values of the indicators projected under the RCP4.5 and RCP8.5 scenarios for the three periods of the Lithuanian climate (2021–2050, 2046–2075 and 2071–2100) are presented, based on the outputs of the four GCM and RCM combinations (Figure 3).

Based on the projected climate indicator values, the average annual temperature is expected to increase by 1.2–1.3 °C according to RCP4.5 and 2.6–2.9 C according to RCP8.5 by the end of the twenty-first century, compared to the current 1991–2020 period [38]. Among the three cities in the country, the strongest warming is anticipated in Eastern Lithuania (Figure 3a). According to RCP8.5, by the end of the century, the air temperature is expected to rise the most in November to January (3.2–4.4 °C), with increases of 1.9–2.9 °C in other months. The average temperature for all winter months would become positive, and temperatures in July and August would exceed 20 °C. It is noteworthy that some temperature indicators projected for the end of the twenty-first century under the RCP8.5 scenario have already been recorded in recent years. The average annual air temperature in 2019 and 2020 reached 9–10 °C in many regions of Lithuania, and the temperature for all winter months in 2019–2020 was positive (with an average winter temperature reaching 2.6 °C). In July 2021, the temperature was 22–23 °C; in August 2022, it was 20–22 °C, and so on. The number of cold days (with a minimum daily temperature ≤ -15 °C) per year is expected to decrease by more than half, and the heating season duration should also decrease. On average, in Lithuania, this reduction by the end of the century will range from 14 to 15 days according to RCP4.5 and up to 31 days according to RCP8.5.

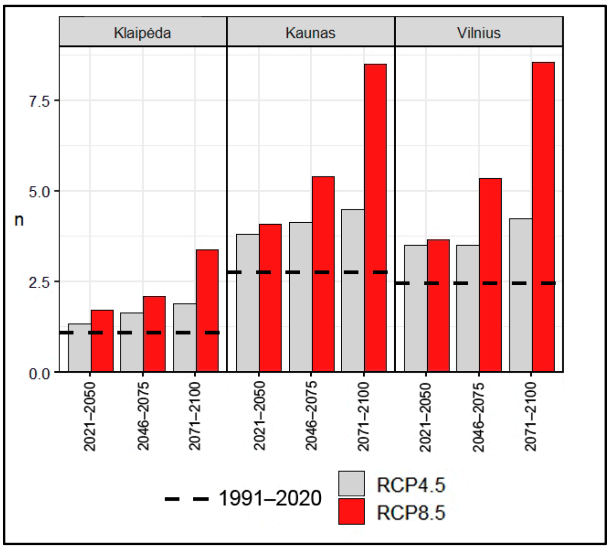
Temperature fluctuations at around 0 °C (freeze–thaw cycles occurring within a single day) cause many adverse effects on traffic conditions, road surfaces and building structures. With the rapid rise in winter temperatures, the number of freeze–thaw cycles is expected to decrease by 18% under RCP4.5 and about 42% under RCP8.5 by the end of the century. A faster reduction in such days is anticipated in the latter half of the twenty-first century.

The number of days meeting the heatwave criteria (a heatwave is defined as a period when the maximum daily temperature reaches 30 °C or more for three or more consecutive days; the average duration of heatwaves may be less than three days, as there may be years without heatwaves) per year is projected to increase compared to the current period, with an increase of 1.6–1.7 times according to RCP4.5 and more than three times according to RCP8.5 (Figure 3b). The increase in the number of tropical nights is expected to be two to three times according to RCP4.5 and up to 7–13 times according to RCP8.5 (Figure 3c). As the climate warms, the number of cooling days for buildings is expected to increase by approximately the same amount as the decrease in the heating season, so the annual energy consumption for building operation should not change significantly. On average, in Lithuania, by the end of the century, the increase in cooling days for buildings is expected to range from two weeks according to RCP4.5 to one month according to RCP8.5.

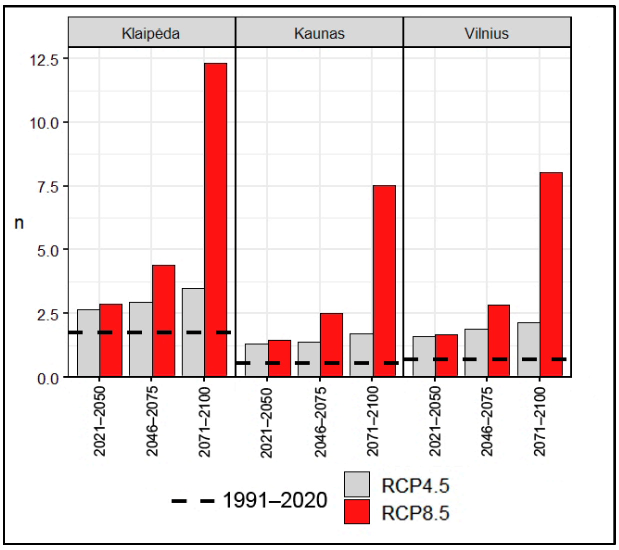
Figure 2. The Baltic Sea region and the analyzed cities in Lithuania—Vilnius, Kaunas and Klaipėda (compiled by the authors).



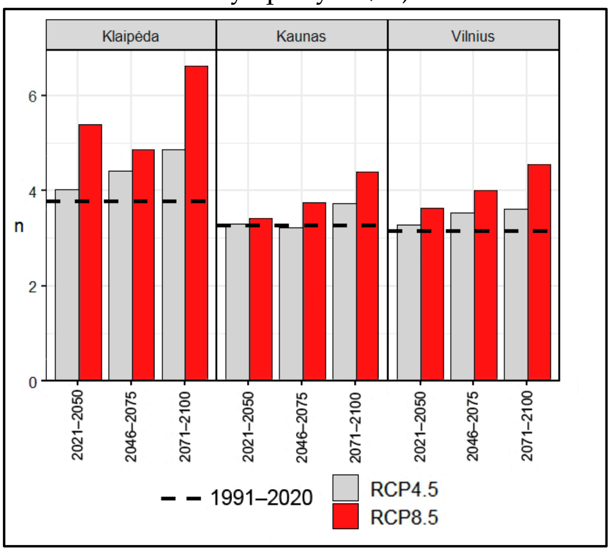
a—average annual air temperature, °C



b—average duration of heatwaves (number of days per year, n)



c—number of tropical nights (daily minimum temperature ≥ 20 °C) per year (n)



d—number of days (n) per year with very heavy rainfall (≥20 mm/day)

Figure 3. Projections for various climate indicators for Klaipėda, Kaunas and Vilnius. The current values of the climate indicators from 1991 to 2020 are shown with a dotted line, while the projected average values for the periods 2021–2050, 2046–2075 and 2071–2100 according to the RCP4.5 and RCP8.5 scenarios are depicted with white and red bars (prepared by the authors).

The projected increase in the average annual precipitation in Lithuania ranges from 42 mm, or 6% (RCP4.5), to 98 mm, or 14% (RCP8.5). The RCP8.5 scenario predicts a more even distribution of seasonal precipitation, with the largest increases in precipitation (more than 20%) expected from October to May, while the precipitation during July and August may even decrease. However, July is expected to remain the rainiest month across most of Lithuania [38]. The number of days with very heavy precipitation (≥20 mm per day) is projected to increase this century from the current 3–4 days to 14 days (28%) under RCP4.5 or up to 34 days (75%) (RCP8.5). The greatest increase is anticipated in Klaipėda (Figure 3d).

By the end of the twenty-first century, the climate models do not predict significant changes in the wind speed or its seasonal cycle. Under the RCP4.5 scenario, the average annual wind speed is expected to decrease by about 0.1 m/s, while, under RCP8.5, it is projected to remain the same as in the current period [38]. Significant changes in the number of calm days (average wind speed per day $\leq$ 1.5 m/s) are also not predicted for this century. Calm days with weak winds during the summer could increase the intensity of urban heat islands. Currently, the average number of such days per year in Lithuania ranges from 5 days on the coast to 18 days in Eastern Lithuania.

This analysis indicates that climatic indicators will have a significant impact on the country's cities. Kaunas and Vilnius, along with other cities in Central and Eastern Lithuania, need to pay attention to the increasing average duration of heatwaves. Klaipėda and other cities in the coastal and western regions should be aware of the growing risk of tropical nights. Cities should also evaluate the increasing intensity of predicted heavy precipitation and other indicators. Assessing these data is crucial for urban planning, construction, green space design and other landscape management issues.

3.3. Extreme Climate Change Phenomena in Lithuania and Their Impacts on People and the Living and Natural Environments

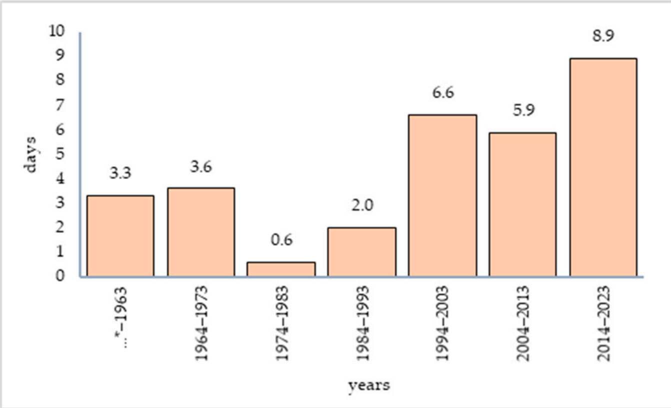
Based on the abovementioned projections of temperature increases, it is likely that extreme climate change events will increase globally, in Europe and in Lithuania. Extreme phenomena such as heatwaves, sudden and intense precipitation and storms can be identified as some of the main events often causing the greatest risks and natural disasters. Each country has regulations defining the thresholds of meteorological phenomena recognized as natural disasters. For example, in Lithuania, based on the established indicators for extreme, catastrophic, meteorological and hydrological events, a heatwave is recorded when the maximum air temperature is equal to or exceeds 30 °C for three consecutive days. Intense rainfall is defined as more than 80 mm of precipitation within 12 h. If the precipitation over a period of five days or less exceeds three times the monthly standard norm, it is recorded as a prolonged intense heavy rainfall event [64].

These and other extreme events have negative effects for cities and their residents; for instance, heatwaves can have various impacts on society, negatively affecting human health and the natural environment [65–72]; the effects on the environment can be both short-term (e.g., forest fires) and long-term (e.g., subsiding of water bodies, species and ecosystem adaptability) [73], as well as causing economic damage due to reduced productivity, increased strain on the healthcare system and higher costs for building cooling [74,75].

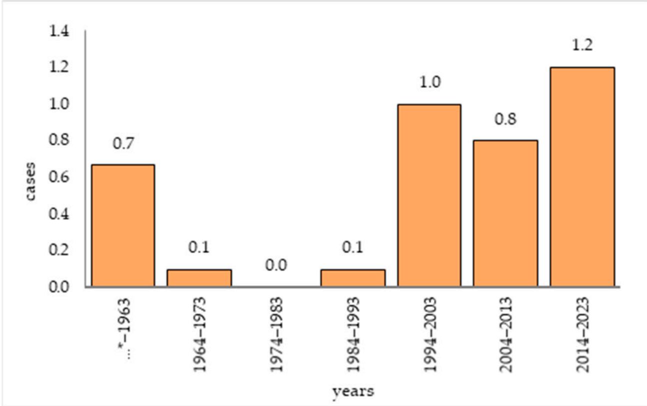
Additionally, sudden and intense or prolonged precipitation can lead to flooding, which also causes significant damage to residents, cities and their surroundings [76,77]. This includes submerged vehicles, buildings and property; severely restricted transportation and water and electricity supply disruptions [77]; economic damage to residents and businesses [78,79]; and negative environmental impacts, such as water pollution, soil erosion, landslides and ecosystem damage [80,81].

To assess the overall scale of extreme events and their impacts, it is necessary to evaluate how their frequency and intensity have changed over time. To this end, the climatic data collected by the Lithuanian Hydrometeorological Service (LHMS) [40], recorded in the selected cities, Vilnius, Kaunas and Klaipėda, since 1961, are reviewed. According to the LHMS data, from 1961 to 2023, a total of 34 heatwaves that affected at least one of the three cities were recorded. The longest and most severe heatwave occurred in Vilnius at the end of July and the beginning of August 1994, lasting 11 days, with three of these days recording extreme heat across all meteorological stations in selected cities. Considering all selected cities, the largest numbers of hot days (with temperatures $\geq$ 30 °C) were registered in Vilnius and Kaunas, where there were, on average, 1.6 hot days per year from 1961 to 1990 and 5.3 hot days per year from 1991 to 2020 in Vilnius, with 5.0 in Kaunas. The fewest heatwaves were recorded across the Baltic Sea region in Klaipėda, with an average of 0.5 hot days per year from 1961 to 1990 and 3.3 hot days per year from 1991 to 2020.

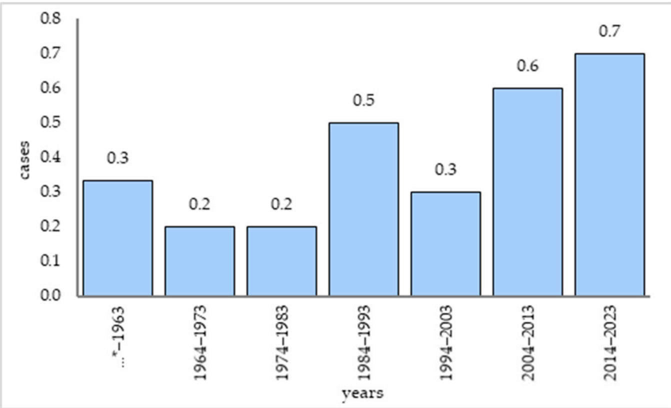
The last three decades reveal a trend of increasing heatwaves in the selected cities. This is evident from both the larger number of days experiencing heat and the increased frequency of their occurrence (Figure 4a,b).



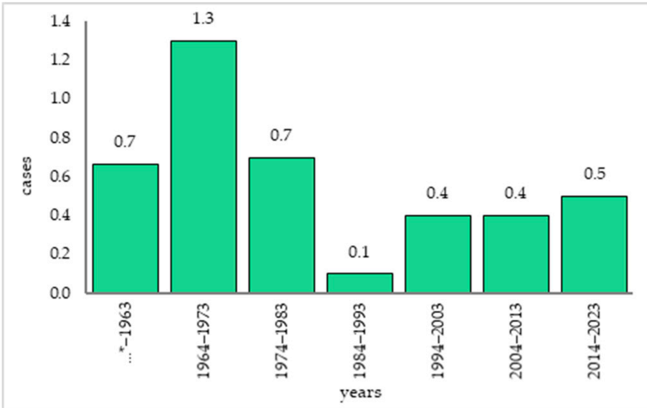
a *—average number of hot days when air temperature is ≥30°C per year



b *—average number of extreme heatwave events per year [1]



c **—average number of heavy rainfall events with rainfall of 50 mm or more in 12 hours or less per year [2]



d *—average number of intense wind events per year [3]

Figure 4. Summary of statistics related to hot days (**a**), heatwaves (**b**), heavy rainfall (**c**) and intense winds (**d**) in selected cities, Vilnius, Kaunas and Klaipėda, in timeframe of 1961–2023. Data indicate the average number of events per year in each decade (prepared by the authors according to LHMS data, 2024 [40]). [1] An extreme heatwave (or heatwave) is defined as a period when the maximum temperature is equal to or exceeds 30 °C for three consecutive days. [2] Heavy rainfall is defined as intense rain exceeding 50 mm within 12 h. [3] Intense wind is defined as wind gust speeds of 28–32 m/s at 10 m aboveground in the Lithuanian mainland territory and 24 meters aboveground in the Lithuanian Baltic Sea economic zone and at the Klaipėda state seaport. * Calculation carried out concerning the number of calendar days according data for all three cities (the same day in every city counted as one day). ** Calculation carried out concerning the number of individual cases according to data for all three cities (each case in every city counted as a separate case). . . .–1963—less than a decade of data; data from 1961 are considered.

Intensifying heatwaves are often accompanied by heavy rainfall and storms, which suddenly affect various parts of the country. Their impact on cities is assessed based on the catastrophic rainfall (≥80 mm in <12 h) and intense rainfall (50–80 mm in <12 h) events recorded by the LHMS in the selected cities, Vilnius, Kaunas and Klaipėda. During the analyzed period of 1961 to 2023, a total of 26 cases of catastrophic and intense rainfall (storms) were recorded in these cities. The largest number of intense rainfall events occurred between 2014 and 2023, with an average of 0.7 per year, or seven over the entire decade.

The 2004 to 2013 period was also notable, with about 0.6 intense rainfall events per year in any selected city (Figure 4c).

Storms, which cause damage to buildings, uproot trees and result in considerable other damage, also pose significant risks to the residential environment. The highest frequency of intense winds, reaching 28–32 m/s, was observed between 1964 and 1973 (Figure 4d). Over the following three decades, the number of storms decreased. The period from 1984 to 1993 was the calmest. Since 1994, the number of storms has increased again. Overall, the frequency of intense winds over the observed period can be considered to be decreasing. This aligns with the previously discussed forecasts, which indicate no significant changes in the average annual wind patterns. Nevertheless, it is important to pay attention to specific extreme wind phenomena such as tornadoes and squalls, which may be confined to convective processes in small areas. Such storms are not always registered by meteorological stations, but the growing damage to buildings, property and forests shows the increasing frequency of them [41].

Compared to the meteorological phenomena discussed, floods in Lithuania were recorded much earlier, starting from 1812. The most extreme floods occurred in the lower reaches and delta regions of the Nemunas River. Statistical data show that over 90% of the extreme and catastrophic hydrological events were caused by natural phenomena such as snowmelt and ice jams during the spring. Significant floods also occurred in the middle reaches of the Nemunas River in Central Lithuania, but their frequency decreased considerably after the construction of the Kaunas Hydroelectric Power Plant in 1960.

Cities located near rivers, such as Rusnė, Kretinga, Klaipėda and Kaunas (especially before 1960) and other residential areas, are the most affected by floods. Flooding often affects roads, homesteads and residential areas in the Nemunas delta and other river valleys.

Overall, the majority of the floods in the country have been caused by snowmelt and ice jams during the spring—amounting to about 75%—while only 15% of the floods were due to intense rainfall [62,81].

To compare the scale of flooding with that of other natural disasters, this article provides detailed statistics on river floods from 1961 to 2023, evaluating the indicators of extreme and catastrophic water level rises at selected hydrological stations near the Nemunas River in Rusnė, Panemunė and Smalininkai and near the River Neris in Buivydžiai (Figure 5).

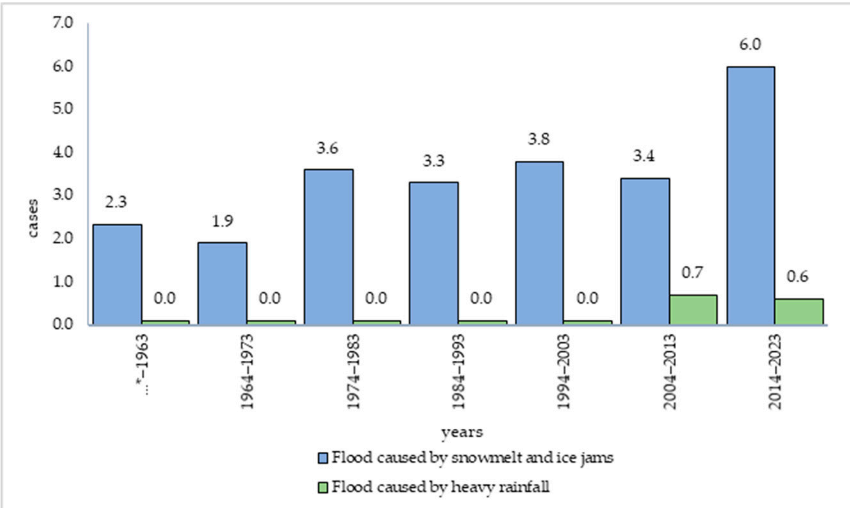


Figure 5. Average number of flood cases per year in Lithuania for selected hydrological stations at the River Nemunas in Rusnė (Atmata, Šilininkai), Panemunė and Smalininkai and the River Neris in Buivydžiai by decade. The graph shows data on flood and extreme water rise levels. Extreme water rise levels are recorded according to the criteria of each water gauging station. A flood is recorded when the area inundated by flood water is equal to or greater than 60,000 ha [81] (prepared by the authors according to LHMS data, 2024 [40]).

The most significant river and other water body floods in the twentieth century occurred in winter or spring due to thawing and drift ice. Floods in the lower reaches of rivers, occurring for centuries, can typically be regarded as natural environmental phenomena. However, in recent decades, floods caused by heavy rainfall during summer and autumn have been distinguished as having a different origin. These rainfall-induced floods are increasingly seen as signs of the broader impacts of climate change [40]. It should also be noted that, due to intensifying rainfall, there are increasingly frequent instances of localized flooding in various parts of cities. This usually occurs due to the large number of impermeable surfaces and the inadequate drainage of sudden high volumes of water. Such localized floods, while not individually recorded, are highly relevant to cities as they pose direct threats to residents, property and infrastructure, as high levels of flood water increase the risk of drowning and damage to vehicles, housing and road infrastructure and utilities [82].

The data registered in the country indicate that, as seen globally, Lithuania is experiencing changes in its weather conditions—rising air temperatures and increased heavy rainfall. This creates conditions for more frequent heatwaves and floods, which particularly affect cities and other residential areas. According to the data of the IPCC, both in the near and distant future, with increasing urbanization and population densities, the negative impacts of heatwaves and floods on residents and their environments are expected to rise, especially if adequate measures to adapt to the changing climate and potential natural disasters are not implemented [18].

For this reason, one way to reduce the vulnerability of cities—the risks of hazards and the scale of the potential damage—is to adapt the environment, i.e., the space in which people live, to be as resilient as possible, especially regarding the increasingly intense and frequent heatwaves and floods.

3.4. Preparation of Cities to Mitigate Risks Posed by Climate Change and Other Potential Threats to People and Urban and Natural Environments

As discussed in the previous sections, the most significant global threat affecting Lithuania is climate change and its associated disastrous phenomena, such as floods, heatwaves, storms, wildfires and epidemics. These climate change-induced or exacerbated phenomena directly impact people and their health, destroy material environments and worsen living conditions.

In addition to natural threats, recent times have also seen the emergence of anthropogenic threats—for example, war, as well as radiation in cases of nuclear power station accidents. The consequences of these threats include air and water pollution, the destruction of ecosystems, harm to people and cities and migration waves. Moreover, threats such as war require massive resources for both weapon production and the reconstruction of destroyed cities, which further accelerates these negative climate changes.

Natural and anthropogenic threats, while differing in nature, are interconnected—they affect public health and alter the living and environmental conditions. They are complementary, often occurring simultaneously and exacerbating each other's impacts; therefore, the overall risk posed by these threats should be assessed and addressed comprehensively, using similar protective measures and infrastructure. The goals of such coordinated threat assessment and management processes are established in the civil safety legislation of various countries. As the list of threats expands and new impacts become apparent, these laws are accordingly reviewed and updated [83–86].

The dangers posed by climate change, war, radiation and pandemics currently present a direct threat to Lithuanian cities and their surroundings. Consequently, the review and assessment of these threats raises the question of the country's preparedness or how the Lithuanian state is preparing to adapt to and mitigate these dangers.

Preparation to combat climate change and the other mentioned threats should occur at two levels: at a national level, in the development of legislative and legal frameworks and their enforcement, and at a municipal level, through the implementation of these legal acts. Laws should address strategic issues, evaluating the nature of the threats, preventive measures and adaptation strategies. They should also establish the requirements for the development of living environments, protective facilities and other infrastructure, which should be achieved through joint efforts among the state and local authorities.

To mitigate climate change threats or adapt to them, key areas include proper land use planning, urban development, green space creation, the protection of natural areas and the formation of green and blue space systems. These functions fall under the purview of the Ministry of Environment of the Republic of Lithuania, which is responsible for drafting relevant legislation and overseeing its implementation. However, an evaluation of the ministry's activities in this area suggests that the legal framework prepared by them does not adequately address climate change and other threats. Moreover, there is no oversight of legal act implementation due to the lack of the necessary resources and expertise a strategic approach to land use planning and a rational land use policy. This is evidenced by an analysis of the institution's structure [87,88] and the uncontrolled land distribution and urbanization processes.

The primary legal document prepared by the ministry that regulates urban development and can significantly respond to ongoing climate change processes is the Republic of Lithuania's Law on Territorial Planning (2014) [89]. This law establishes the goals of rational land use and defines the requirements for land development. Based on this law, territorial planning documents—master and detailed plans—are prepared. Thus, responsible institutions, by purposefully utilizing the provisions of the law, can address specific climate change challenges.

To complement the national legal framework with climate change tasks, the Parliament of the Republic of Lithuania adopted the National Climate Change Management Policy Strategy in 2012 [13]. This strategy outlines goals for the mitigation of and adaptation to climate change, aimed at increasing ecosystems' sustainability, developing a system of protected areas and an ecological framework and restoring and enhancing natural landscape elements. However, despite these provisions, the strategy does not have the desired impact on the Law on Territorial Planning.

Climate change-related goals were only incorporated into the Law on Territorial Planning in 2021 [90], and no measures required for their implementation are specified in this law or other normative documents. The law does not address the need to modify urban planning, conduct land reorganization, apply measures to protect natural areas, reduce land occupation by new developments and other matters. Consequently, the implementation of the goals set out in the legal acts to mitigate climate change remains undefined, unclear and challenging to achieve.

In 2009, the Republic of Lithuania's Law on Climate Change Management was adopted [15]. It started to regulate efforts to reduce CO_2 emissions, but this only affected specific economic sectors and did not address fundamental climate change issues in the urban sphere. More concrete tasks were outlined in the National Climate Change Management Agenda, approved in 2021 [14], which aims to plan settlements, urban areas and spaces based on sustainable development and green infrastructure principles, ecosystem evaluation, nature conservation and resilience enhancement. However, their implementation depends on the Law on Territorial Planning, which is not yet prepared for this purpose.

The fact that the goals set regarding the mitigation of or adaptation to climate change are difficult to achieve is reflected in the ongoing land use changes in the country. According to the land use statistics and an analysis of municipal master plans, it has been determined that, over the past two decades (2002–2023), the area of built-up land has increased from 1879 km^2 to 2434 km^2, while the population has decreased from 3443 million to 2857 million [91,92]. The master plans prepared during this period foresee approximately 7000 km^2 of urbanized and urbanizable areas, which is about three times the existing built-up area (Figure 6). This situation indicates negative urbanization trends, leading to urban sprawl—the unplanned formation of new areas and the occupation of natural land surfaces—which unreasonably paves the way for new traffic flows, air pollution, heat islands and more.

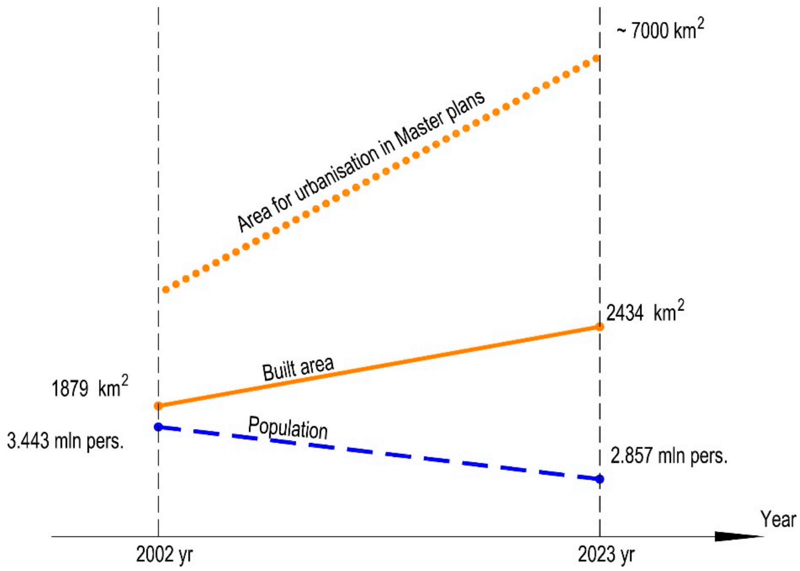


Figure 6. Changes in the urban and demographic situation of the country in the period 2002–2023 (prepared by the authors according to the data of the Register of Territorial Planning Documents of the Republic of Lithuania [42], State Data Agency [91] and Land Bank [92]).

One of the main reasons for such unplanned urban expansion is the territorial planning documents prepared by municipalities—master, detailed and other plans—whose clients, creators and approvers are the municipalities themselves. Consequently, municipalities, without central institutional oversight, adhere to their own laws, with the primary goal of occupying as much land as possible for land use changes—land-trading businesses and greater options for construction site selection. These goals are often overshadowed by the desire to attract investments and increased municipal competitiveness, but they are entirely unsupported by sustainable development and the need to strengthen the resilience of territories against the negative impacts of climate change. The most pronounced example of this process lies in metropolitan areas, particularly along the coast—the most valuable recreational areas of the country—where the planned urbanized area is about four to six times greater than the existing built-up area (Table 1, Figure 7).

Table 1. Urban development in master plans (prepared by the authors). Data generated from an analysis of the master plans of municipalities, the Register of Territorial Planning Documents of the Republic of Lithuania [42] and the Land Bank [92].

No.	County	Number of Municipalities	Existing Built-Up Land, 2023, km^2 [80]	Area Planned to Be Urbanized Under the Master Plans of 2002–2023, km^2 [42]	Planned Change Under the Master Plans of 2002–2023, %
1	Alytus County	5	163.5	181.15	110.80
2	Kaunas County	8	406.64	329.46	81.02
3	Klaipėda County	7	241.1	685.21	284.20
4	Marijampolė County	5	162.19	257.61	158.83
5	Panevėžys County	6	248.15	376.29	151.64
6	Šiauliai County	7	259.96	647.63	249.13
7	Tauragė County	4	119.4	376.67	315.47
8	Telšiai County	4	142.31	320.07	224.91
9	Utena County	6	214.11	541.59	252.95
10	Vilnius County	8	477.33	620.14	129.92
	Total	60	2434.69	4335.86	178.09

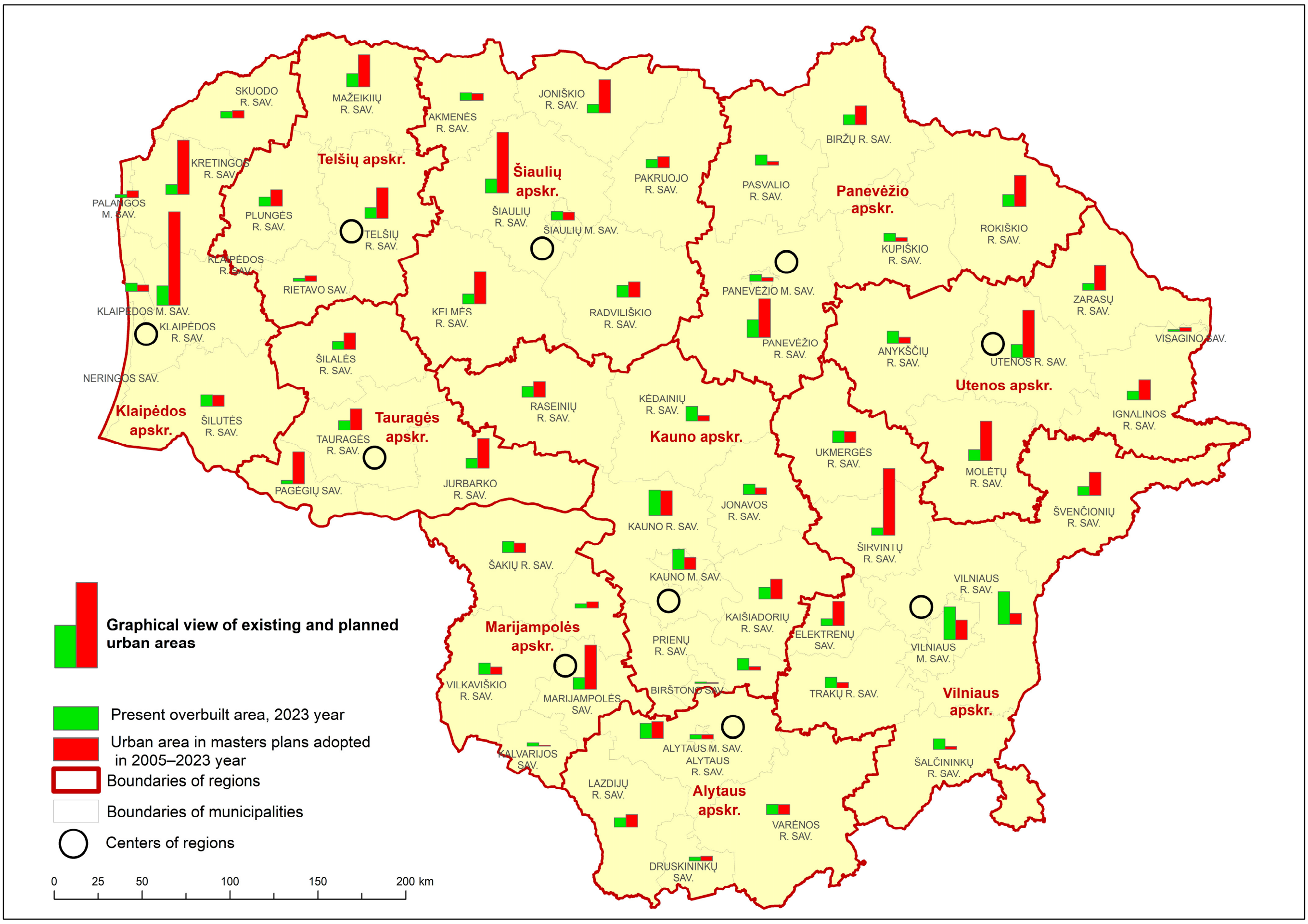


Figure 7. Diagram of existing built-up areas and areas planned for urbanization in 2002–2020 (prepared by the authors; refer also to Table 1).

The current trends in Lithuania are contrary to those in foreign countries, which consistently pursue sustainable development. Countries such as Germany, Belgium, France, Luxembourg, Austria and Switzerland set land occupation limits, while others, such as the United Kingdom and Belgium, plan to undertake land conversion or similar measures [93–96]. In this way, these countries are implementing the objectives of the 2011 and 2013 EU directives [9,10], which aim to halt the increase in land uptake and soil sealing by buildings and infrastructure by no later than 2050, a goal that cannot be identified for Lithuania. Despite this situation, as previously mentioned, the responsible state institutions in Lithuania (the Ministry of Environment) are not fulfilling their assigned functions.

An important component of the urban structure in Lithuanian cities is industrial areas, which, in total, cover approximately 1000 km^2. For the development of these areas, the EU set objectives in 2020 to maintain the global competitiveness of European industry, fully digitalize it and achieve climate neutrality for European industry by 2050. Although these objectives are considered in the country's action plans and aim to strengthen regions, promote industry and encourage the circular economy [97], the further development of industrial areas is essentially unregulated by any legal act. Consequently, aside from the development of a few industrial parks, most of the country's industrial areas are developed spontaneously—industrial facilities are placed without a system, justification or coordination, often disregarding the surrounding residential, valuable natural or recreational areas [42]. The country has declared priorities for information technology, the health and biomedical sectors, chemistry, energy and other high-value-added industries, but, without organized development, the conditions for sustainable and environmentally friendly urban structures cannot be established. Appropriate organization is hampered by the uncoordinated and disconnected management of industrial development by different institutions. The Ministry of Economy and Innovation handles the attraction of industrial enterprises, the Ministry of Internal Affairs allocates funds for infrastructure development and the Ministry of Environment sets urban planning requirements—including industrial zones—while specific territorial development decisions are made by municipalities [87,88,98].

A very important part of the urban structure that can significantly mitigate the effects of climate change and other threats is green spaces and their system. The targeted development of this system, establishing differentiated groups of green spaces based on their importance and distribution, was enshrined in the Law on Green Areas (2007) [99] and the Norms for Separate Green Areas for Recreational Purposes (2007) [100]. However, to avoid reserving land for green spaces and adapting to the construction business, the Ministry of the Environment, through its own initiative, abolished this system in 2022. To this end, the green space regulations have also been revised. The maximum distance from a resident's home to a green space was increased from 300 meters to 1 kilometer, and the minimum green space area per resident was reduced—for example, in large cities—from 20 m^2 to 12 m^2 [101]. Only after protests from architects and the public were some of the previously set green space standards partially reinstated in 2023 [101]. Nevertheless, it is evident that the planning of green spaces is not adequately protected and evaluated in terms of potential threats.

To mitigate the effects of climate change, a significant role can be played by the network of key natural areas—the natural framework—which includes a system of river valleys, slopes, wetlands, forests and other ecologically sensitive areas. Although the natural framework is granted legal status and its management is regulated by the Natural Framework Regulations (2007) [102], its protection is often overlooked in territorial development. According to master plan decisions, new urban development structures are planned within natural framework areas. Consequently, residential and industrial construction is carried out, the relief is altered, wetlands are filled and other activities that reduce the natural characteristics are performed. This all has negative consequences for the functioning of the ecological network and the geological structure. This is particularly evident in construction on slopes; here, not only is the natural environment destroyed, but there is also a risk to the buildings themselves from potential landslides, collapses and other issues.

Negative trends are also occurring in protected areas, which ecologically form a particularly important type of natural territory (nature reserves, regional parks, Natura 2000 areas, etc.). The use and management of these areas is regulated by the Law on Protected Areas (1993) [103], and its implementation is overseen by the State Service for Protected Areas, established under the Ministry of the Environment. Although the law imposes stricter requirements for land use, significant construction opportunities are still available—for the reconstruction of, for example, former homesteads, the development of recreational complexes and the expansion of new residential zones. This creates conditions not only for the necessary and purposeful functioning of the areas but also for the intensive occupation and development of valuable natural territories. This is often legitimized according to preferences by making changes to the management plans of the largest complex protected areas—national and regional parks—without substantial oversight or expert evaluation.

One of the most stable areas in the country should be forest land, the protection of which is established by the Forestry Law (1994) [104]. According to this law, forest areas cannot be reduced, except in exceptional cases of public necessity, which are overseen by the State Forest Service established under the Ministry of the Environment. However, recent concerns have arisen regarding the rational management of forests, particularly regarding decisions to increase clear-cutting areas—such as clear-cutting protective and recreational forest parts, among others. It has been noted that, since 2010, forests in the country have been absorbing less carbon dioxide from the atmosphere [105]; thus, such activities not only lead to deterioration in the ecological conditions of forests and the country's ability to mitigate climate change impacts, but also indicate that forests are becoming commercial assets.

There are also numerous questions regarding decisions made in flood risk management. In Lithuania, flood risk and hazard maps were prepared in 2015 according to the 2007 EU Floods Directive [43], but they do not provide a basis for the avoidance of new flood risks. Based on these maps, the legal regulations identify high-, medium- and low-probability flood zones; however, these are not properly assessed as there are fairly flexible opportunities for new construction. According to the data from the master plans of Lithuanian municipalities, the urban development planned in medium- and low-probability flood areas currently covers about 115 km^2, meaning that, under such legal construction conditions in river valleys, the water shore relief is raised or otherwise important natural environments for flood risk reduction are altered (Table 2).

Table 2. Urban development planned in flood-prone areas (prepared by the authors). Data generated from an analysis of the master plans of municipalities and maps of flood risk areas (Register of Territorial Planning Documents of the Republic of Lithuania [42], maps of flood risk areas [43], geo-object data GDR250 [106]).

No.	County	Flood Risk Area, km^2 *	Built and Planned Construction in Flood Risk Areas, km^2 **	Percentage of Built and Planned Construction in Flood Risk Areas, %
1	Alytus County	79.027	3.285	4.16
2	Kaunas County	252.475	25.143	9.96
3	Klaipėda County	511.540	28.398	5.55
4	Marijampolė County	80.076	5.367	6.70
5	Panevėžys County	113.920	8.553	7.51
6	Šiauliai County	59.485	3.392	5.70
7	Tauragė County	315.879	26.321	8.33
8	Telšiai County	28.365	1.627	5.74
9	Utena County	56.337	3.20	5.68
10	Vilnius County	67.709	10.458	15.45
	Total	1564.813	115.744	7.40

* Data calculated using the following sources: 0.1% probability flood risk zone boundaries [43]; geo-object data GDR250 [106]. ** Data calculated using the following sources: 0.1% probability flood risk zone boundaries [43]; urban areas designed in the master plans of the territories of municipalities [42].

The situation is even more complex in the riparian buffer zones of water bodies that are not subject to flooding but are primary areas of the natural framework. Although these areas have specific boundaries with strict ecological requirements, they do not restrict urban development opportunities at all. To fulfil the wishes of the owners and the business of land trading, urban development in these areas is planned to take place on an even larger area of the waterfront compared to flood areas designed for urbanization. Overall, it may be stated that spatial planning does not adequately address the mitigation of climate change's impacts or adaptation to them.

From an urban perspective, it is particularly important to assess the country's preparedness for anthropogenic threats, such as war and radiation hazards. The main infrastructure for protection against these threats includes shelters, refuges and other emergency facilities, which have recently gained significant relevance following the construction of the Astravets Nuclear Power Plant (in Belarus, 30 km from the capital Vilnius; started in 2012 and activated in 2020) and the Russian military invasion of Ukraine in 2022.

Lithuania's readiness for war, radiation threats and other emergencies is regulated by the Republic of Lithuania's Law on Crisis Management and Civil Protection (1998, 2024) [16]. This law details the responsibilities and competencies of various institutions, but it is unclear who is specifically responsible for implementing it. The law includes provisions for the preparation of emergency management plans and warning systems; the necessity of shelters, collective protection structures and refuges; and the accumulation of reserve measures. However, an evaluation of the implementation of these requirements reveals that there are no major shelters in the country that are capable of protecting against severe war, radiation threats and other hazards. According to data from the Fire and Rescue Department (FRD) under the Ministry of the Interior for 2024 [44], there are 3448 refuges in the country, capable of temporarily housing 934,939 (32%) members of the country's population (Table 3).

Table 3. Shelters and refuges in the country (data source: Fire and Rescue Department under the Ministry of the Interior (FRD), 2024 [44]).

No.	County Name	Number of Municipalities	Population	Shelters	Refuges			
				Number (Units)	Number (Units)	Area (m^2)	Capacity (People)	Percentage of the Population Housed in Shelters, %
1	Alytus County	5	134,201	0	136	73,837	47,583	35
2	Kaunas County	8	585,480	0	1228	384,319	243,248	42
3	Klaipėda County	7	339,972	0	216	94,210	62,307	18
4	Marijampolė County	5	134,668	0	356	119,454	74,348	55
5	Panevėžys County	6	209,071	0	120	42,405	28,256	14
6	Šiauliai County	7	266,960	0	265	125,074	79,942	30
7	Tauragė County	4	90,578	0	68	30,464	20,354	22
8	Telšiai County	4	130,918	0	89	25,924	16,927	13
9	Utena County	6	126,326	0	166	53,127	35,417	28
10	Vilnius County	8	868,341	0	804	496,337	26,558	38
	Total	60	2,886,515	0	3448	445,151	934,939	32

Only in recent years, with the onset of the war in Ukraine, has there been an effort to address the development of shelters and refuges. In 2024, a legislative act is being prepared to establish technical regulations for the construction and installation of shelters and refuges [107]. However, this legislation is intended solely for the setting of additional requirements for newly constructed buildings with different functions and does not address the systematic formation of protection infrastructure. It does not consider the placement of shelters, accessibility distances, sizes, the urban structure, the population density, etc., which indicates that the organized urban preparedness for the development of protection infrastructure is lacking.

These and other laws and regulations adopted at the national level partly take into account international and EU objectives related to climate change and emergencies, but the quality of the legislation suggests that it is fragmented, lacking a framework, and is inadequate. These regulations are intended to be implemented by local municipalities with little responsibility and oversight, offering them the freedom to make various decisions.

In summary, it can be stated that no efforts have been made in Lithuania to protect its cities, the environment and its residents from the potential negative impacts of climate change and other mentioned threats. This situation needs to be fundamentally changed, starting with urban planning (improving the regulatory framework), spatial planning (coordinating national land use policy implementation at the municipal level) and control (ensuring high-quality, rational and sustainable territorial development in line with state strategies for sustainable land use).

4. Discussion

Questions and Premises for Improvement of Urban Structure, Considering the Dangers of Climate Change and Other Potential Threats

Considering the reviewed state of Lithuania and the risks posed by climate change, war, radiation, pandemics and other threats to the country's cities and their environments, as well as the state's inadequate preparedness to mitigate or address these threats, there is a need to provide some premises to tackle these issues. Based on these premises, upon completing the ongoing urban and climatological research, it is anticipated that proposals will be prepared to address the mentioned threats and issues.

As previously mentioned, the response to the discussed threats and their consequences typically occurs at two levels: national (legislative framework development and enforcement oversight) and municipal (implementation of legislation). The effectiveness of the adaptation to climate change and other threats can depend on the coordinated efforts of these two levels of governance.

However, as discussed in the previous section, the real situation in the country is quite complex. The primary national law governing urban planning, urban development and rational land use, which is prepared and overseen by the Ministry of the Environment, barely addresses the threats posed by climate change and the opportunities to mitigate or protect against them. Urban planning and development in the country continue with outdated methods—planned areas are divided into separate plots for development, without public green spaces, civil protection facilities or other structures necessary for the safety of the city's population. Additionally, to expand construction areas, green spaces are being reduced, despite their importance as a key element of the urban structure in mitigating the negative impacts of climate change. Moreover, the Law on Territorial Planning entirely omits the planning of industrial areas, their layouts and regulatory frameworks for their structures, even though industrial enterprises occupy significant portions of urban areas. It should be noted that the planning of industrial area sizes in the country is not legislated and regulated but is outlined in city master plans, with the intention that these areas might be offered to investors in the future.

Regarding the unchecked urban development, it is crucial to highlight that such processes are influenced by local municipalities seeking to plan as many construction plots as possible, regardless of the sustainable development requirements. This possibility arises from the fact that the Ministry of the Environment does not regulate or oversee these urbanization processes.

In addition to the main law, which almost completely ignores the risks of emerging threats, there are environmental and conservation regulatory documents that, while not emphasizing the threat risks, essentially help to mitigate the negative impacts of these threats. Such legal documents include the laws on the natural framework, forestry, water bodies and riverbank protection, floodplain protection and other regulations. Nevertheless, natural areas are being developed to create more plots for construction and land trade—water bodies and river banks, natural framework areas and even floodplain lands, with forests, are also being cleared for this purpose.

Construction in particularly sensitive natural areas is also being studied in other foreign countries. For example, although cities in many countries are located in flood-prone areas and the risk of flooding is always present, construction continues in these areas [108]. Deforestation is an equally pressing issue [109]. Such cases demonstrate that countries that have to comply with international directives for sustainable development and climate change do not create all of the necessary legal preconditions for their implementation [110].

In the context of land conservation within the European Union, Western European countries such as Belgium, Germany, France and Denmark are more notable for their efforts to limit land loss. Meanwhile, in Eastern European countries, less attention is given to limiting land occupation, with priority given to economic factors [111].

Considering the uncontrolled and unreasonable urban development in the country, along with the lack of protective measures, it may be stated that there is no sufficient state policy to limit urban expansion and ensure rational land use.

Based on the earlier analysis of the country's territorial planning and related laws, and with the aim to create climate-neutral and resilient urban areas, it is essential to have an appropriate legislative and regulatory framework. This is also supported by the findings of researchers from other countries, addressing issues related to stopping urban sprawl, reducing land occupation and enhancing towns' resilience to the negative impacts of climate change. Separate research highlights that the targeted management and control of urban planning by the relevant authorities at all levels of the government is crucial to achieving zero environmental impacts, as well as for other transformations related to sustainable land use [30,33,95].

The main urban development document—the Law on Territorial Planning—should primarily establish the direction for urban planning, focusing on limiting unjustified urban expansion to promote compactness and rational, efficient land use [31,95]. This would protect large natural and agricultural areas from urbanization, significantly reduce traffic and create better conditions to address ecological, economic and social issues [31,112].

Based on the previous analysis, it can be concluded that Lithuania and its cities are not prepared to confront climate change, war, radiation, pandemics and other potential future threats and their consequences. The urban structure is not adapted to these challenges, lacking public universal spaces, green areas, green corridors connecting internal spaces with the outside and civil protection facilities and infrastructure.

In this situation, the sustainability of the urban structure is the primary issue, and a model must be developed to address these urban, functional, social, economic and ecological concerns.

When developing an urban structure planning model, it is crucial to consider recommendations from the key international documents—climate change agreements [7,8] and the sustainable development goals [113].

Additionally, when developing a new model for urban structural development, it is essential to evaluate new urban development strategies, trends, urban searches and proposals. One of the most significant urban developments is the New Urbanism movement, which began in the 1980s, emphasizing the need to halt urban sprawl and promote functional zoning flexibility (1980) [114]. The development of New Urbanism has led to new and progressive directions in the shaping of the urban fabric [115]. This trend is supported by the actively developed ideas of sustainable urban development [116]. One such idea in this area is Moreno's concept of the 15-minute city, where key functional points of the city—work, services, health, education and leisure—can be reached within 15 min on foot or by bicycle [117,118]. This creates an opportunity to reduce vehicle traffic, improving the environmental conditions, quality and more. Regarding future cities, most authors (Moreno, Garde, Riffat) outline key directions for their urban development: the conservation of planned areas, their rational use, the compactness and efficiency of urban structures, a reduction in transport and an improvement in the ecological conditions [115–117]. A particular emphasis is placed on preserving natural areas and creating green spaces as a crucial factor in combating the negative impacts of climate change. These ideas, related to city development, urban planning, the conservation of areas, a reduction in urban sprawl and so on, as well as proposals to reduce and mitigate the threats of climate change that align with the focus of this work, can be fully endorsed and followed.

To address the chaotic urban development, it is assumed that the planned and spatial structures of future cities should consist of a sustainable urban structural unit or complex. This would comprehensively address all vital social, environmental, economic and civil safety issues related to residential environment formation.

Such an urban complex should be a territorial unit within the city structure, bordered on all sides by public transport streets, which should connect the complex to the city's overall planning structure while limiting internal traffic. The urban structure of this complex should include a distinct territorial unit formed from residential blocks grouped around an indispensable multifunctional public space—the urban core. This space would concentrate essential territorial elements and objects, including a leisure, recreational and play area; a center for community interaction, social activities and child education; a shelter complex for protection against threats (war, radiation, etc.); and a management and information center for the sustainable urban structure.

The formation of such a compact urban structure would also allow for the rational resolution of issues related to the complex's engineering systems, information communications, internet services, digitization and other concerns. It would also allow for convenient and safe pedestrian movement, both within the complex and on public transport routes.

Establishing and implementing a complex, sustainable urban structure would enable the future protection of cities and their inhabitants from the current and potential threats and contribute to the creation of climate-neutral future cities. The analysis of the target urban complex and its formation is one of the immediate tasks in this area of study.

Continuing these studies, it is necessary to develop a planning model for a sustainable urban structural territorial unit—an urban complex —and to propose its incorporation into urban planning regulatory documents.

This article marks the beginning of research focused on the formation of the urban structure of Lithuania's residential areas, taking into account the impacts of climate change and other threats. This article is introductory in nature, reviewing the existing and potential future threats, as well as examining how the state of Lithuania is preparing or is prepared to combat these threats.

As part of the mentioned research, a climatological survey of various types of urban areas are currently being conducted to determine the relationship between urban structures and the impacts of climate change in the country. Based on urban and climatological research and existing global experience, as previously mentioned, it is anticipated that a functional urban model for a new sustainable urban structural territorial unit will be developed. This model will be published, discussed and incorporated into regulatory and methodological urban planning documentation for use in the country.

Considering that the problems posed by climate change and other threats, along with their increasingly negative consequences, are a long-term process that will require constant adaptation, it is assumed that research on these issues should be continued.

5. Conclusions

- In recent decades, key climate change indicators have reached record highs, with a growing trend. It is projected that global warming will continue to intensify in the near future (by 2040) and is likely to not only reach but potentially exceed the 1.5 °C threshold. Considering the climate response scenarios for GHG emissions, the most likely climate warming projections for 2081–2100 are 1.4 °C under the low GHG emissions scenario (SSP1–1.9), up to 2.7 °C under the intermediate GHG emissions scenario (SSP2–4.5) and 4.4 °C under the very high GHG emissions scenario (SSP5–8.5). Projections indicate that neglecting GHG emissions could lead to catastrophic consequences for the entire Earth, making it essential to pursue the lowest warming scenario to avoid these outcomes.
- According to various climate change scenarios, by the end of the twenty-first century, the temperatures in the Baltic region will rise more than the global average temperature due to significant warming during the winter season. It is expected that, by the end of the twenty-first century, the winter temperatures will be 3–9 °C higher and the summer temperatures will be 1.5–6.0 °C higher compared to the end of the twentieth century. This will result in a series of other climatic phenomena changes, including increased precipitation frequencies, more hot and tropical nights and others. These climatic factors will significantly affect the quality of the living environment, depending on how cities are prepared to adapt to the emerging climate challenges.

- Extreme climate phenomena—heatwaves, sudden and intense precipitation and storms—can be identified as major events that frequently pose the greatest risks and cause natural disasters in the country. The analysis of the period from 1961 to 2023 in Lithuania shows a trend of increasing heatwaves—more days with prolonged heat and the intensified recurrence of these events. Intensifying heatwaves are accompanied by an increase in heavy precipitation cases, often resulting in particularly dangerous storms. Due to the warming climate and increasing precipitation, the likelihood of spring floods is expected to decrease, while the number of floods caused by heavy rainfall is expected to rise significantly.
- Catastrophic climate change, war, pandemics and other threats differ in nature, but their destructive impacts on urban areas, the environment and people are quite similar. Therefore, the measures and infrastructure for protection against these threats are analogous. This requires a green space near residential areas with safety equipment that is not only intended for protection against these threats but also can be used for residents' leisure, recreation and social interaction.
- It has been established that there is a lack of preparation in the country's cities to mitigate the dangers posed by these threats. Urban planning in the country's cities, rational land use, the creation of green spaces and the protection of natural areas from development are not being carried out. In addition, the drafting of legislation in this area and the supervision and control of its implementation by central authorities (the functions of the Ministry of the Environment) are also absent.
- Therefore, municipalities, as the primary implementers of laws and projects, operate according to their own 'provisions' in the absence of state oversight, with the main goal of preparing as many plots for construction as possible. As a result, there is the unreasonable allocation of land, disregarding legally protected and valuable natural areas, floodplains, water protection zones and so on. This substantially reduces or eliminates opportunities to combat climate change.
- As the country's municipalities are undergoing an uncontrolled, unjustified urbanization process, overdeveloping agrarian and valuable natural areas, this is reducing the landscape's resilience to the adverse effects of climate change. It is therefore essential that such indiscriminate development be stopped and that privatized sites of particular conservation value be expropriated. Moreover, urban areas should not be divided into separate plots or blocks, which cannot individually provide adequate living, recreation, activity and safety conditions.
- Given the existing and potential future threats, urban planning should follow different urban principles. Instead of separate districts, cities should be planned as sustainable structural complexes, integrated units connected by public transport links to the entire city. Such a structural urban unit would consist of groups of building blocks, combined into a whole with green spaces containing recreational and social areas, as well as protective infrastructure capable of safeguarding all residents of such a structural urban unit. The implementation of such sustainable urban structures would create conditions for the development of socially, ecologically and economically viable future cities, protected from existing and potential future threats.

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Abbreviations

SCN	standard climate normals
CMIP	Coupled Model Intercomparison Project
RCP	Representative Concentration Pathway
GCM	global climate model
RCM	regional climate model
LHMS	Lithuanian Hydrometeorological Service
FRD	Fire Rescue Department under the Ministry of the Interior of the Republic of Lithuania
WMO	World Meteorological Organisation
COP	UN Climate Change Conference
UNFCCC	United Nations Framework Convention on Climate Change
IPCC	Intergovernmental Panel on Climate Change
GHG	greenhouse gas
SSP	shared socioeconomic pathways
RSL	relative sea level
CN	climate normals

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