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Mariia KANDII, PhD Student
ORCID ID: 0009-0007-9358-4277
e-mail: mariakandij@knu.ua
Taras Shevchenko National University of Kyiv, Kyiv, Ukraine

Serhii NAZARENKO, PhD, Junior research associate
ORCID ID: 0000-0003-3367-5875
e-mail: Serhii.Nazarenko@lei.lt
Lithuanian Energy Institute, Kaunas, Lithuania

Viktor SAMOILENKO, DSc (Geogr.), Prof.
ORCID ID: 0000-0002-0327-1477
e-mail: viksam1955@gmail.com
Taras Shevchenko National University of Kyiv, Kyiv, Ukraine

CLIMATE-NEUTRAL URBOGEOSYSTEMS: THEORETICAL BASES OF RESEARCH

Background. ***Eurointegration processes require Ukraine to join the EU initiatives, one of which is the European Green Deal, which aims to achieve climate neutrality by 2050. Climate neutrality and related concepts are currently being actively discussed in the global scientific community. Ukrainian academic literature also contains studies on this topic, but there is a noticeable lack of comprehensive works. The article explores the theoretical bases for studying climate neutrality in general and in relation to urbogeosystems in particular.***

Methods. ***The main method used is bibliometric analysis of publications retrieved from Web of Science Core Collection database. The bibliometric data were processed using the network analysis method with the help of VOSviewer software, on the basis of which the main research areas were determined.***

Results. ***It was revealed that more publications are devoted to carbon neutrality than to climate neutrality, while net-zero carbon emissions are not studied as often as net-zero greenhouse gas emissions. In contrast, Ukrainian scientists more commonly use the concept of climate neutrality. The calculations made showed that climate neutrality seems to be more relevant for regional-scaled and national-scaled assessments, while the concept of carbon neutrality can be used for studying systems in which the energy sector is the main source of greenhouse gases emissions.***

Conclusions. ***In this article, the main concepts are defined and their usage in the scientific literature is analysed. The countries where such research is most actively conducted are identified, and the achievements of Ukrainian scientists are analysed. The difference between climate neutrality, net zero emissions, carbon neutrality and net zero carbon emissions is described. Based on the analysis of the component composition of emissions, the expediency of using these concepts depending on the specifics of the study is substantiated. The main problems that arise when choosing the object and subject of research are outlined, and ways to solve them are presented. The main approaches to determining the coverage of sources of greenhouse gas emissions and sequestration in the study of urbogeosystems are analyzed. The application of these approaches in the recommendations for greenhouse gas inventories is investigated. The article substantiates the prospects of studying climate neutrality for both large industrial centers and small urbanized systems, which are easier to achieve climate neutrality.***

Keywords: ***climate neutrality, urbogeosystem, net-zero emissions, greenhouse gases, bibliometric analysis.***

Background

On 11 December 2019, the European Green Deal (EGD) was presented, which is a roadmap of policies and measures that aim to transform Europe into the first climate-neutral continent by 2050 (The European Green Deal, 2019). As part of the European integration movement, Ukraine must join all EU legislative initiatives, including the EGD. Currently, our country is initiating a dialogue on cooperation within the framework of the EGD, which makes Ukrainian research in the field of climate neutrality a high priority, especially within Earth sciences. The most substantial studies seem to be on those systems, that are most harmful to the climate. In terms of economic sectors, such systems belong to the energy sector, while in terms of geosystems, they include urban geosystems (urbogeosystems) as places with the highest concentration of greenhouse gases emissions and the lowest level of sequestration.

The aim of the study is to analyse the basis for climate neutrality research of urbogeosystems. To achieve this goal, the following tasks should be addressed: (1) to define the categorical and conceptual framework, (2) to analyse the use of concepts related to climate neutrality in scientific literature, (3) to review Ukrainian scientific literature devoted to the selected topic, (4) to determine the spatial coverage for the urbogeosystems' climate neutrality studies, (5) to outline the main approaches to determining the greenhouse gas sources and removals in urbogeosystems.

Literature review. The fundamental concepts of climate and carbon neutrality are highly debated issues in foreign scientific literature. Under these conditions, a number of generalised works on this topic exist. One of the first literature reviews is an article (Huovila et al., 2022), in which the concepts of a carbon-neutral city are analysed, including the definition, assessment approaches, as well as the challenges and driving forces of the transition to carbon neutrality. In (Seto et al., 2021) a detailed analysis of four approaches to determining the urban carbon footprint is provided and three strategies and seven ways to achieve deep decarbonisation of cities are described, including the practical examples of their implementation. There are also numerous works of the Ukrainian authors devoted to the prospects of achieving climate neutrality in various sectors of the economy (Borodina, 2024; Grod, & Reznikova, 2023; Maksimova, & Nastase, 2024, etc.), regional features of the "green transition" (Nazaruk, Polyanskyi, & Ostroushko, 2022; Shevchenko, 2023; etc.). A more detailed analysis of Ukrainian research on this topic is provided in the Results section. However, there is a noticeable lack of comprehensive works in the field of climate neutrality and net-zero emissions in Ukrainian language.

Methods

Considering the purpose of the study, the main method used is bibliometric analysis. Publications were retrieved from the Web of Science Core Collection (Web of

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Science™) scientometric database. The bibliometric data was processed using network analysis with the VOSviewer software (Van Eck, & Waltman, 2014). This application creates maps based on network data, in this case based on bibliometric data. The results of the keyword search in the Web of Science Core Collection database were exported to text files with a separator (.csv). Since there is a limit on the number of exported records (no more than 1,000), while the number of search results in most cases exceeded this limitation, the results were downloaded as separate files with further aggregation using Excel.

Results

Regulatory acts, in particular EU legislation, do not contain a clear definition of the concept of climate neutrality, despite its widespread usage. According to (The European Green Deal, 2019), achieving climate neutrality is described as achieving net-zero greenhouse gas emissions for the EU as a whole. Despite the intuitive clarity of this definition, the need to specify it further remains.

Four interrelated terms are widely used in scientific literature and legislative acts: "climate neutrality", "carbon neutrality", "net-zero emissions" and "net-zero carbon emissions". These concepts can be divided into two groups: firstly, "neutrality" vs "net-zero emissions"; secondly, "carbon" vs "climate".

The difference between "neutrality" and "net-zero emissions" is the following. According to literary sources (Huovila et al., 2022; Seto et al., 2021), net zero emissions are defined as a state of a particular system (territory, industrial facility) in which greenhouse gas emissions are minimised. The latter implies that emissions are reduced by 60–100 % compared to the base year, and the amount emitted into the atmosphere, i.e. 40–0 % respectively, is removed from the atmosphere through compensatory measures within a given system. Neutrality is defined as a state of the system in which the same conditions for reducing greenhouse gas emissions are met as in the previous definition. However, the volume emitted into the atmosphere can be offset by measures both within a given system and by purchasing the necessary removal volumes from other systems (Huovila et al., 2022). Therefore, achieving net-zero emissions is a more ambitious goal.

The difference between "carbon" and "climate" concepts lies in the list of gases that are taken into account. In the case of carbon neutrality and net zero carbon emissions, the balance of nitrogen dioxide is calculated only, while the concepts of climate neutrality and net zero emissions take into account the balance of all greenhouse gases. According to (Kyoto Protocol…, 1977), these include carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons and sulphur hexafluoride. Each approach has its advantages and disadvantages.

The study of carbon balance is methodologically simpler. Carbon dioxide is the main product of fossil fuel combustion and the main gas absorbed and deposited by plants. For example, we can use the calculation of pollutant emissions into the atmosphere, carried out on the basis of the methodology approved by the Ministry of Environmental Protection and Natural Resources of Ukraine (Collection of emission indicators…, 2004), for a 1 MW solid fuel boiler operating during the heating season and using 400 tonnes of wood per year as fuel. Under these conditions, the emission volumes in tonnes per year are the following: suspended solid particles of undifferentiated composition – 1.400; carbon monoxide – 0.940; nitrogen oxides (nitrogen oxide and nitrogen dioxide) in reference to nitrogen dioxide – 0.984; methane – 0.025; non-methane volatile organic compounds – 0.221; nitrogen (1) oxide – 0.020; carbon dioxide – 503.357. Thus, the emissions of carbon dioxide in the example above exceed the total emissions of all other substances by 140 times. Therefore, for an urbogeosystem where the energy sector is the main source of emissions, the "carbon" approach would be appropriate to apply.

The study of all the greenhouse gases balance of is more challenging. First, more sources and sinks must be taken into account. Second, the cumulative effect of these gases must be calculated. To accomplish the second task, the carbon dioxide equivalent (CDE) parameter is used. CDE is calculated by multiplying the volume of emissions of a particular greenhouse gas by the global warming potential of that gas – a coefficient that reflects the degree of influence of that gas on the greenhouse effect (GWP). GWP values are given in Annex III to the Report of the 19th Conference of the Parties to the United Nations Framework Convention on Climate Change (Report of the Conference…, 2014). Carbon dioxide is taken as the reference (GWP=1), and the coefficients of other greenhouse gases are greater than one. For example, for methane GWP=25, for nitrogen (1) oxide GWP=298, for sulphur hexafluoride GWP=22800 (Report of the Conference…, 2014). For Ukraine, official data on the overall greenhouse gas balance are presented in the Draft National Inventory of Anthropogenic Emissions from Sources and Absorption by Sinks of Greenhouse Gases in Ukraine for 1990-2021 (Draft National Inventory…, 2023). According to this document, emissions in 2021 in million tonnes of CO_2 equivalent amounted to: carbon dioxide – 227.3; methane – 71.6, nitrogen (1) oxide – 43.8; hydrofluorocarbons – 1895.2; sulphur hexafluoride – 48.9. According to these data, hydrofluorocarbon emissions have the greatest impact on the climate system in Ukraine, rather than carbon dioxide. Therefore, when studying carbon neutrality or net-zero emissions on national scale, the use of the "carbon" approach will not be representative.

Neutrality implies a zero greenhouse gas balance. If emissions exceed sequestration, the system is referred to as climate-negative or carbon-positive, if sequestration exceeds emissions, it is referred to as climate-positive or carbon-negative.

As the mentioned concepts have their own specificity, the question as to which of them are more frequently used by scientists and in what context arises. To address this issue, a search in the Web of Science Core Collection scientometric database was conducted. The search was performed on 29 May 2025 using the "Topic" search parameter. The selected words were connected using "+" aggregator in order to be perceived as a single term. The exception was the "Net+Zero Carbon" keyword, since the search results for this query should cover both "net zero emissions of carbon" and "net zero carbon emissions". The keywords "Net+Zero" and "Net+Zero+emissions" were supplemented with the conjunction "NOT" to exclude results that refer exclusively to net-zero carbon emissions. As can be seen in Table 1, carbon neutrality is more widely used concept than climate neutrality. Regarding net-zero emissions, the opposite is observed: there are fewer works devoted to net-zero carbon emissions. In the block of "climate" concepts, the term net-zero emissions is used more often, while in the block of "carbon" concepts, the term neutrality is used more frequently. These trends are fully reflected in the distribution of works devoted to urban research. In the block of "positivity" and "negativity" concepts, "carbon" terms prevail. The following trend can also be observed: works are devoted more frequently to the negative balance of greenhouse gases (when sequestration prevails) than to the positive one.

Table 1

The use of terms related to climate neutrality in scientific literature, based on Web of Science Core Collection scientometric database (Web of Science™, https://www.webofscience.com/)
(author search parameters)

Keyword	Number of publications	Keyword	Number of publications
Climate+neutral	1,070	Carbon+neutral	**7,405**
Climate+neutrality	1,234	Carbon+neutrality	**13,396**
Net+Zero NOT Net+Zero+Carbon	**10,386**	Net+Zero Carbon	5,500
Net+Zero+emissions NOT Net+Zero+Carbon+emissions NOT Net+Zero+emissions+Of+Carbon	**2,764**	Net+Zero+Carbon	1,391
Climate+positive	100	Carbon+negative	**1,191**
Climate+negative	28	Carbon+positive	**156**
Climate+neutral city OR Climate+neutral urban	182	Carbon+neutral city OR Carbon+neutral urban	**602**
Net+Zero city OR Net+Zero urban NOT Net+Zero+Carbon	**914**	Net+Zero+Carbon city OR Net+Zero+Carbon urban	131

The issues of climate neutrality and net-zero emissions of cities are most actively investigated in the People Republic of China, the United States, European countries (the United Kingdom, Italy, Germany, Spain), Australia, Canada, India, and Japan (Fig. 1, A). Co-authorship of publications mainly reflects the geographical principle: co-authors represent countries within the same region in most cases (e.g., Southeast Asia, Latin America, Europe).

Ukrainian works devoted to the problem of climate neutrality also exist. A search in the electronic catalogue of the Vernadsky National Library for these queries yielded a total of 6 results, which mainly relate to the field of economics, while an additional search for "net zero" yielded no results.

A search for national studies was also conducted using the Google Scholar platform. The request "climate neutrality" (in Ukrainian) yielded 209 publications, while the request "carbon neutrality" resulted in 114 studies. Consequently, in contrast to their foreign counterparts, Ukrainian scientists more commonly espouse the concept of climate neutrality. However, a more detailed analysis of the publications revealed that in some studies, these terms are considered synonymous (Kurepin, 2024).

In terms of subject area, most national studies can be classified into one or more of the following categories: (1) climate neutrality of specific economic sectors, (2) legal aspects of climate neutrality, (3) climate neutrality and digitalisation, (4) climate neutrality of particular cities/regions, (5) the impact of war on climate neutrality. The first block is dominated by studies on the climate neutrality of the energy sector (Borodina, 2024; Nechaeva, & Babak, 2025; Orekhova, & Fedorchuk, 2024) and the development of climate-neutral business (Grod, & Reznikova, 2023; Maksimova, & Nastase, 2024). The second block is devoted to studies of both Ukrainian (Ivanyuta, & Yakushenko, 2022; Krasovsky, 2024; Vaolevska, & Myshchak, 2025) and foreign legislation (Ivaschenko, Turchyn, & Tsebenko, 2024; Kovbas, Strutynska-Struk, & Zetko, 2025). The third block presents research that emphasises the close interaction between digitalisation and the "green transition" (Maksimova, & Nastase, 2024; Orekhova, & Fedorchuk, 2024). The fourth block contains a number of studies for particular cities and regions. For example, the prospects for the spatial development of Lviv's urban system with the aim of increasing climate neutrality have been analysed (Nazaruk, Polyanskyi, & Ostroushko, 2022). Another study (Koinova, & Pitsyshyn, 2025) analyses the greenhouse gas balance for Lviv, with a focus on the volumes of emissions. An assessment of the community's vulnerability to climate change has been developed for Vinnytsia (Shevchenko, 2023). The war on the territory of Ukraine resulted into the development of the fifth direction. The focus area includes the impact of ongoing military actions on the components of climate neutrality and on international climate policy (Pavko, 2023), as well as the prospects for implementing the idea of climate neutrality during the post-war reconstruction of Ukraine (Borodina, 2024).

In order to identify the subjects of foreign publications, an analysis was conducted using VOSviewer software. In light of the limitation imposed by Web of Science on the number of records that can be downloaded, keywords with fewer results were selected, namely: "Climate+neutral", "Net+Zero+emissions NOT Net+Zero+Carbon+emissions NOT Net+Zero+emissions+Of+Carbon" (a single query comprising three keywords connected by the NOT operator), "Carbon+neutral" and "Net+Zero+Carbon". The frequency of the author's keywords in each search result was analysed, and the five most frequently mentioned keywords were selected, excluding those that completely or almost completely repeat the keyword searched for. The analysis revealed that the keywords "climate change", "renewable energy" and "sustainability" were the most frequently mentioned in all search results. In the search results for the keyword "Climate+neutral", the European Green Deal (EGD) was among the top five results, indicating its significant role in promoting climate neutrality. The most frequently used keyword in the search for "Carbon+neutral" is "biomass", as carbon sequestration in biomass and biomass combustion are important components of the carbon balance.

A separate analysis was conducted on publications dedicated to the concepts of climate neutrality and net-zero emissions within the context of urbogeosystems. Keywords that appeared more than 20 times were selected for further analysis, while the keywords "city", "neutrality" and "net-zero" were excluded from the analysis because they were included in the query. Consequently, the following keywords were identified as the most frequently occurring and having the strongest connections with others (Fig. 1, B): performance, energy, CO2 emissions, impact, renewable energy, sustainability, emissions. It can thus be concluded that energy is the most frequently studied sector of the economy, and that emissions receive greater attention than sequestration under emission/sequestration processes. The following keywords also indicate the direction of research: housing (69 mentions), transport (27 mentions), health

(20 mentions), land use (25 mentions), water (29 mentions). A considerable number of works are dedicated to legislation and urban planning. A study of the author keywords revealed that those most frequently used were sustainability, renewable energy, climate change, and energy efficiency.

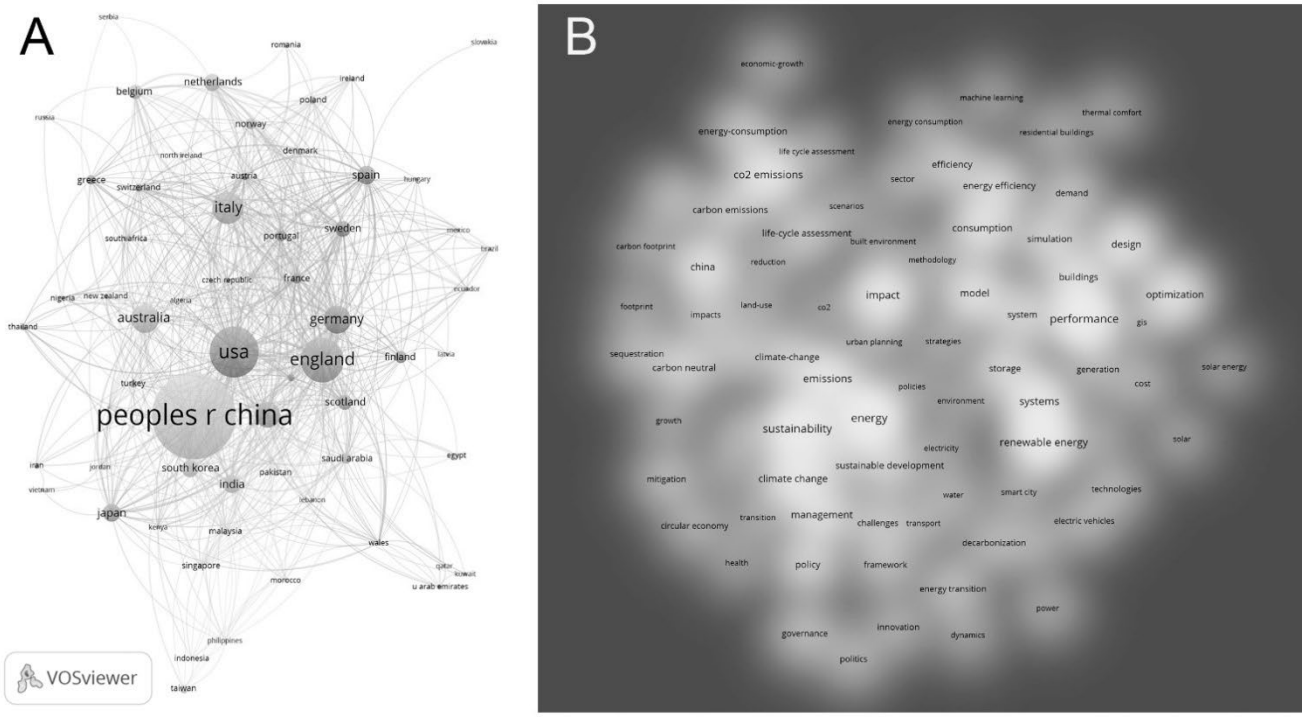

Fig. 1. The analysis of publications on greenhouse gases balance in urbogeosystems (cities) using VOSviewer software: distribution of publications by countries and co-authorship links (A), keyword recurrence (B)

When conducting research on the climate neutrality of urbogeosystems, it is crucial to define the scope of the study, encompassing geographical boundaries, the temporal framework, the gases to be analysed, and the emission sources (Global Protocol for Community-Scale…, 2021). The geographical boundaries of the study refer to the territory for which the calculations will be made. Depending on the tasks set, it can be a separate city within its administrative boundaries, a community, or a region. The duration of the programme is typically one year. The gases analysed encompass the seven gases listed in the Kyoto Protocol in the context of assessing climate neutrality or net-zero emissions. Alternatively, if the focus is on achieving carbon neutrality or net-zero carbon emissions, analysis may be limited to carbon dioxide. The most challenging aspect concerns the identification of the sources of emissions and sinks.

Urbogeosystems are characterised by interconnectedness, with numerous export-import links that facilitate the exchange of resources and energy with external systems. In particular, the supply of electricity and heat, water, food and building materials contains "hidden imports" of greenhouse gases: their production may cause greenhouse gas emissions outside the urbogeosystem, but the final consumption of gases may take place within it. Furthermore, the products and services of the urbogeosystem have the potential to result in greenhouse gas emissions in other systems. The accounting for these flows forms the basis for distinguishing four approaches to defining a net-zero emissions city (Seto et al, 2021):

1. Spatial approach (territorial source-based accounting). This approach exclusively considers greenhouse gas emissions and their removal from the atmosphere within the geographical boundaries of the urbogeosystem. Given that statistical data is usually aggregated for a settlement, this approach is very convenient. Therefore, it seems to be incomplete, as it does not reflect hidden greenhouse gas imports. The spatial approach is utilised, in particular, to evaluate the climate neutrality of urbogeosystems based on land use data. (Page et al, 2021).

2. Infrastructure approach (community-wide infrastructure supply chain greenhouse gases footprinting). This approach takes into account both greenhouse gas emissions and sequestration processes within the urbogeosystem, as well as greenhouse gas emissions generated outside its boundaries in the supply chains of key infrastructure and food flows. The relevance of this approach is evidenced by the fact that, according to (Ramaswami et al, 2016), energy, water supply, transport, housing and construction, waste management, food and urban green spaces account for 90% of greenhouse gas emissions in cities. These sectors usually contain significant amounts of hidden greenhouse gas imports. The infrastructure approach is used in the PAS 2070:2013+A1:2014 standard under the name "direct plus supply chain (DPSC) methodology" (Specification for the assessment…, 2014).

3. Consumer approach (consumption-based accounting). The key point of this approach is to take into account greenhouse gas emissions in all goods and services consumed within the urbogeosystem. The consumer approach is similar to the infrastructure one, yet it encompasses a broader spectrum of imports. Greenhouse gas flows associated with exports of goods and services outside the urbogeosystem are not taken into account. This approach is used in the PAS 2070:2013+A1:2014 standard under the name "consumption-based (CB) methodology" (Specification for the assessment…, 2014).

4. Total approach (total community-wide greenhouse gases footprinting). This approach is the most comprehensive and complicated to implement. It considers greenhouse gas flows in all goods and services imported into urbogeosystem and consumed whithin its boundries (consumer approach) and greenhouse gas flows contained in goods and services exported by the city.

The selection of the approach depends on the available data and the purpose of the study. In (Global Protocol for Community-Scale…, 2021) using the first three approaches is suggested, with separate reporting at each level.

Depending on the principle used to aggregate emissions data, two approaches can be distinguished: accounting can be performed either by emission source category (sector-based) or by end consumer (consumption-based). The difference is that in the first approach, emissions are associated with the primary producer of the product, while in the second, they are associated with the end consumer (Global Protocol for Community-Scale…, 2021; Specification for the assessment…, 2014). For example, if a hypothetical thermal power plant supplies electricity to a hypothetical chemical plant, carbon dioxide emissions from electricity generation will be attributed to the energy sector using the first approach and to the chemical industry using the second one. According to data (Global Protocol for Community-Scale…, 2021), cities account for 75 % of greenhouse gas emissions from energy production. Six main sectors of greenhouse gas emissions in cities are identified in (Global Protocol for Community-Scale…, 2021): (1) energy, (2) transport, (3) waste management, (4) industrial production, (5) agriculture, forestry, other land use, (6) other emissions that occur outside the city due to processes within the city.

In terms of research focus, two approaches can be distinguished: bottom-up and top-down. In the first approach, calculations are made by estimating the total greenhouse gas emissions from all sources and removing at sinks for the system. The second approach uses greenhouse gas flow data for a larger area (e.g., regional or national level), which is scaled to the system of interest. Both approaches provide insight into the overall greenhouse gas balance of an urbogeosystem, but the bottom-up approach provides a better understanding of the sources of emissions and effective ways to reduce them (Global Protocol for Community-Scale…, 2021).

Spatial assessment of greenhouse gas emission and sinks by land use classes is common. This approach is used both for regional-level research (Holmberg et al., 2021) and for local research on urbogeosystems (Page et al., 2021). This approach has a number of advantages. It allows to assess the impact of land use changes on the greenhouse gas balance and also takes into account natural and anthropogenic objects that are an important component of the balance, such as blue-green infrastructure (Page, 2021).

Discussion and conclusions

The paper summarises the theoretical foundations of research on the climate neutrality of urbogeosystems. As a candidate for membership of the EU, Ukraine needs to join all EU initiatives, including the EGD, which makes research on this topic particularly relevant. The scientific novelty of the study is due to the fact that, despite active discussion of the issue of climate neutrality in global science, there is a noticeable lack of generalised studies in Ukrainian scientific literature. Most Ukrainian researches focus on issues such as climate neutrality in certain sectors of the economy, legal aspects of climate neutrality, climate neutrality and digitalisation, climate neutrality in particular cities/regions and the impact of war on climate neutrality.

In (Giacomelli et al., 2025), a thorough analysis of the literature on climate neutrality and urban planning was carried out using the Scopus database. Despite the narrower focus of the study and the use of a different scientometric database, some of the results obtained were similar to ours. For example, there was a coincidence in the leaders among countries in terms of the number of publications (the People Republic of China ranked first, the United States second). The further ranking is slightly different: in (Giacomelli et al., 2025), the top five leaders include Germany, the United Kingdom and Italy, while according to our results, they are the United Kingdom, Italy and Australia, with Germany in sixth place. However, the difference is insignificant and is related to the use of different scientometric databases, as well as different research focus and methodology.

Four related concepts are used to describe the greenhouse gas balance in a given system: climate neutrality, carbon neutrality, net-zero emissions and net-zero carbon emissions. The difference between these concepts relates to the list of greenhouse gases analysed and the mechanisms for achieving balance, particularly with regard to the possibility or impossibility of offsetting emissions outside the system. An analysis of scientific literature indexed by Web of Science showed that most studies refer to carbon neutrality and net-zero emissions. Considering the difference between climate and carbon neutrality, researchers emphasise the greater representativeness of the former concept. Thus, (Guntuka et al., 2024) emphasise the inadequacy of achieving carbon neutrality to effectively combat climate change, as it is important to take other greenhouse gases into account as well. In (Krammer, Dray, & Köhler, 2013) it is reported that the use of biofuels in aviation will reduce carbon emissions, but overall greenhouse gas emissions, estimated using GWP, will increase. We fully agree with the thesis that carbon neutrality studies are limited in comparison with climate neutrality, but we justify their acceptability for studying systems in which the energy sector is the main source of greenhouse gas emissions.

The keyword analysis revealed that research on neutrality and net-zero emissions for urbogeosystems typically focuses on energy, particularly renewable energy, sustainable development, greenhouse gas emissions, including carbon dioxide, as well as such areas as construction, transport, health, land use, water use, and urban planning.

Research on the balance of greenhouse gases in the urbogeosystem requires the definition of the object and subject of the study, namely its geographical boundaries, time frame, gases under study and emission sources. The choice of the first three components seems to be typical, while the problem of emission sources identification is solved in numerous ways. Based on the consideration of hidden greenhouse gas import and export flows, there are four approaches to defining an urbogeosystem with net-zero emissions: spatial, which is limited exclusively to sources of greenhouse gas emissions and sequestration within the geographical boundaries of the system; infrastructure, which takes into account hidden imports of greenhouse gases in the supply chains of key infrastructure and food systems; consumer, which takes into account greenhouse gas emissions in all goods and services consumed within the urbogeosystem; and total, which adds hidden greenhouse gas exports to the consumer approach. The choice of approach depends on the purpose of the study and the available data, with the infrastructure or consumer approach usually recommended.

Aggregating emissions data could be proceeded using the sector-based or the consumption-based approach. The first one means aggregation is performed by emission source category, and the second implies the aggregation by end user. Depending on the focus of the study, the following approaches are distinguished: bottom-up, which uses calculations of indicators based on data on emission/sequestration sources in a given system, and top-down, which involves the use of data for a larger region in which the system is located. Another widespread method is greenhouse gas balance investigation by land use classes.

Research into greenhouse gas balance in urbogeosystems seems to be relevant. On one hand, there is definitely a need to focus on big industrial centres as the most climate-negative systems. On the other hand, it is also crucial to study small urban systems, which can more easily achieve climate neutrality. The lower cost of measures aimed at achieving greenhouse gas balance for such systems increases the probability of implementing these measures, and the possibility of transforming them into climate-positive systems with subsequent participation in the carbon quota market will create additional motivation for the community to make a green transition. In Ukraine, particular attention should be paid to urbogeosystems that have been affected by the war, as the principles of the green transition are easier to implement in the process of rebuilding destroyed infrastructure than in the restructuring of existing infrastructure.

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Марія КАНДІЙ, асп.
ORCID ID: 0009-0007-9358-4277
e-mail: mariakandij@knu.ua
Київський національний університет імені Тараса Шевченка, Київ, Україна

Сергій НАЗАРЕНКО, д-р філософії, мол. наук. співроб.
ORCID ID: 0000-0003-3367-5875
e-mail: Serhii.Nazarenko@lei.lt
Литовський енергетичний інститут, Каунас, Литва

Віктор САМОЙЛЕНКО, д-р геогр. наук, проф.
ORCID ID: 0000-0002-0327-1477
e-mail: viksam1955@gmail.com
Київський національний університет імені Тараса Шевченка, Київ, Україна

КЛІМАТИЧНО НЕЙТРАЛЬНІ УРБОГЕОСИСТЕМИ: ТЕОРЕТИЧНІ ЗАСАДИ ДОСЛІДЖЕННЯ

В с т у п . ***Євроінтеграційні процеси вимагають від України долучатись до ініціатив ЄС, однією з яких є Європейський зелений курс, за мету якого править досягнення кліматичної нейтральності до 2050 р. Кліматична нейтральність та дотичні до неї поняття нині активно обговорюються у світовій науковій спільноті, у вітчизняній науковій літературі також наявні дослідження із вказаної тематики, проте відчувається брак узагальнювальних робіт. У статті досліджено теоретичне підґрунтя вивчення кліматичної нейтральності як загалом, так і щодо урбогеосистем зокрема.***

М е т о д и . ***Основним методом є бібліометричний аналіз публікацій, проіндексованих базою Web of Science Core Collection. Бібліометричні дані було оброблено методом мережевого аналізу за допомогою програмного забезпечення VOSviewer. На основі отриманих результатів було визначено переважні напрями досліджень.***

Р е з у л ь т а т и . ***Було виявлено, що вуглецевій нейтральності присвячено більше праць, ніж кліматичній нейтральності, в той час як нетто-нульові викиди вуглецю вивчаються не так часто, як нетто-нульові викиди парникових газів. На відміну від закордонних колег, українські дослідники частіше використовують поняття кліматичної нейтральності. Розрахунковим методом було обґрунтовано, що для досліджень на регіональному та національному рівнях використання концепції кліматичної нейтральності є більш інформативним, у той час як концепція вуглецевої нейтральності може бути успішно використана при дослідженні тих систем, основним джерелом викидів парникових газів в яких виступає енергетичний сектор.***

В и с н о в к и . ***Наведено визначення основних понять та проаналізовано їх уживаність у науковій літературі. Визначено країни, в яких такі дослідження проводяться найбільш активно, проаналізовано напрацювання українських учених. Описано різницю між кліматичною нейтральністю, нетто-нульовими викидами, вуглецевою нейтральністю та нетто-нульовими викидами вуглецю. На основі аналізу компонентного складу викидів обґрунтовано доцільність використання цих понять залежно від специфіки дослідження. Окреслено основні проблеми, які постають при виборі об'єкта та предмета дослідження, наведено шляхи їхнього розв'язання. Проаналізовано основні підходи до визначення охоплення джерел викидів та секвестрації парникових газів при дослідженні урбогеосистем. Досліджено застосування таких підходів у рекомендаціях щодо інвентаризації парникових газів. Обґрунтовано перспективність вивчення кліматичної нейтральності як великих промислових центрів, так і невеликих урбанізованих систем, яким легше досягти кліматичної нейтральності.***

К л ю ч о в і с л о в а : ***кліматична нейтральність, урбогеосистема, нетто-нульові викиди, парникові гази, бібліометричний аналіз.***

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