Vol. 3 No. 2 (2025)

Spectrum of Engineering Sciences

SPECTRUM OF ENGINEERING SCIENCES

Online ISSN
3007-3138
Print ISSN
3007-312X

Bridging Nature And Building Energy Demands Through Bio-Solar Green Roofs: A Review

Azhar Iqbal[1*]
Department of Electrical Engineering, University of Gujrat, Gujrat, Pakistan. Corresponding Author Email: azharuetian@gmail.com
Shoaib Rauf[2]
Department of Electrical Engineering, University of Gujrat, Gujrat, Pakistan.

Abstract

The impact of climate change offers a critical challenging research for sustainability. With an increasing awareness about bio-solar green roofs as a natural solution, a large gap still exists in knowing their part to get urban resilience and sustainability. The research has reviewed prevailing perspectives of bio-solar green roofs to improve urban sustainability. Our paper provides the literature review on bio-solar green roofs in the context of climate change, employing the "bio-solar green roof" and climate change" keyword in the Web of Science repository. A bibliometric analysis is used to see the trends of research from 39 published documents meeting selected criteria, like language, and type of publication type etc. Repeating subject included selected keywords like urban heat islands (UHI), thermal comfort, carbon footprints, and human well-being. This study proposes the Bio-Solar Green Roof Framework (BSGRF), which join such ideas into a systematic way for resilience and sustainability in urban areas. The research also supports for mainstreaming bio-solar green roofs into adaptation planning, creating sustainable and resilient communities in line with the Sustainable Development Goals presented by United Nations.

Spectrum of Engineering Sciences
Online ISSN
3007-3138
Print ISSN
3007-312X
SPECTRUM OF ENGINEERING SCIENCES

Introduction

Climate change is a global concern, spotted by increasing temperatures, sea levels rises, and recurring extreme climatic events. Such events have badly impacted our ecosystems and human beings [1, 2]. The global warming has changed rainfall patterns and has led to increase and continuous flooding events. Moreover, rate of urbanization has increased which is further enhancing impacts of urban floods. This gives emphasis to the need to effectively adapt precaution measures, like as implementing bio-solar green roofs [2]. Owing to this, it is becoming an important discussion, talks, and policy considerations theme regarding urban environment, energy saving, sustainability and infrastructure too. Consequently, applying such adaptation measures along with mitigation strategies followed by some realistic solutions is necessary for urban sustainability.

Building energy use serves an essential part in facilitating the development of urban heat islands (UHI) because of the human-caused environmental heat that urban areas encounter [3]. Building needs for energy, that account for roughly fifty percent of all building usage of energy [4], are being significantly affected by global warming and lead in increased greenhouse gas emissions per year coming from the combustion of petroleum and natural gas [3]. Meanwhile, meteorological parameters like temperature increase and dust accumulation are impacting output of a solar PV system [5].

Concentrations of greenhouse gases (GHGs), particularly carbon dioxide, have significantly increased in recent decades, leading to global warming and energy disproportion. Human actions such as flaming fossil fuels, rapid

Spectrum of Engineering Sciences
SPECTRUM OF ENGINEERING SCIENCES
Online ISSN
3007-3138
Print ISSN
3007-312X

industrialization, and deforestation are the main contributors to the rise in GHGs [6]. This has resulted in a global temperature (average) increase of 0.85 °C or 0.65–1.06°C from 1880 to 2012, with a 0.74±0.18°C increase in the past hundred years from 1906–2005 [7]. These changes can have significant impacts on public health, energy and water demands, and ecosystems [8]. Various climate impact studies focus on precipitation, temperature, and also on evaporation as key indicators of climatic change in a region. Analyzing trends in historical climate data is a crucial step in evaluating the climate conditions of a particular region, providing an overall assessment of the fluctuations in such climate variables over a specific period of time. The primary goal of our analysis is to know the general trend (increase or may be decrease) and magnitude of change, rather than delving into the internal dynamics of changing climate, such as how the climate is evolving over time [9].

Long-term climate datasets spanning from decades to hundreds of years are necessary for trend analysis as well as climate change assessments. Mann-Kendall test (MK) [10] along with Innovative Trend Analysis (ITA)[9] has been frequently used by earlier studies to see the impact of changing climate in various regions across the globe. Both MK and ITA are quite robust trend analysis techniques, and some past studies have proven its better performance before especially in hydro-meteorological kind of analysis such as rainfall [9], temperature and evapotranspiration [11], and groundwater level [12] in various parts of globe.

In view of the impacts of changing climate, policymakers are attempting to decrease the power consumption of both new and existing buildings [13]. Establishing methods of mitigation that

Spectrum of Engineering Sciences
Online ISSN
3007-3138
Print ISSN
3007-312X

decrease ecological problems, particularly the UHI caused on by urbanization, that include urban greening (green roofs) and extending renewable energy resources, is one feasible and significant region [14]. Bamdad (2023)[15] stated that how the potential of saving energy by green roofs could change over time and it will present annual energy reserves for moderate climates in the future. More studies include roof greening [16], facade greening [17], and tree planting [18]. Trees on the streets help little to UHI mitigation in crowded commercial areas due to their canopies are unable to shade taller buildings. Therefore, rooftop solar photovoltaic (PV) system integration research and green roofs are gaining momentum [13].

Green roofs cultivate suitable vegetation or media, serving as a potential bridge between nature and urban environments [19] while contributing to the creation of a high-quality environment [20]. Recent green roofs, as depicted in Figure 1, consist of multiple layers, including vegetation, growing media, filters, drainage systems, and waterproof membranes, enhancing the filling capacity of conventional roofs by blocking the transfer of heat from the sun [20]. Additionally, the evapotranspiration process by vegetation generates a cooling effect by absorbing solar heat and converting it into evaporation through biological mechanisms [17].

Based on the vegetation types available and the thickness of the substrate/beneath layer, there are basically two forms of green roofs available: intensive and extensive. Enormous green roofs bear a thin layer of substrate of 15 cm with a few types of grasses and plants available on top. On the other hand, intensive green

Spectrum of Engineering Sciences
Online ISSN
3007-3138
Print ISSN
3007-312X
SPECTRUM OF ENGINEERING SCIENCES

roofs /roof gardens with denser substrate layers and some taller vegetation, including small trees or grasses [21].

Numerous studies have investigated the impacts of green roofs in reducing indoor temperatures and utilization of energy, considering some important factors such as climate change [20], types of green roof [21], maintenance situations, structure height and density [22]. Many existing studies have utilized the EnergyPlus software, produced by Sailor et al (2012)[23], which model the behavior of vegetated roofs (green roofs) using an energy balance approach [24]. Extensive green roof design has shown a greater potential to deal with UHI effects due to lesser solar energy absorption in the daytime [20]. Additionally, the irrigation intensity has been identified as a major factor influencing green roof performance as proven by Heusinger et al., (2018)[25]. Also, researches by [16, 26, 27] have shown that integrating a green roof plus solar PV system can give favourable results. In this scheme, PV panels are placed above the cover of green roof at calculated spaces and projections (angles), allowing sufficient sunlight to reach the PV cells while providing some vegetation growing space. Another research found the synergistic nexus among nature-based mechanisms and solar energy for European climates [28]. Southern part of Europe, measures like rooftop PV fitted over cool/ green roofs, PV shadings, or urban trees have shown good agreements in warmer climates. While, cities with mid-to-high-latitude have shown positive impacts by integrating rooftop PV green roofs or green spaces.

The PV modules and green roofs integration can offer mutual benefits, enhancing both PV electricity generation and the ecological green roof environments [29]. However, feature such as

Spectrum of Engineering Sciences
Online ISSN
3007-3138
Print ISSN
3007-312X
SPECTRUM OF ENGINEERING SCIENCES

climate conditions, vegetation types on green roofs, installation techniques, and PV panels' height can influence this relationship. Findings have revealed that vegetation possess a potential to cool photovoltaic generation systems, which may boost the power generation and offer weather-insulation [30, 31]. In contrast, another study [29] found that although PV-fitted areas may encourage plant growth, but, electricity generation was not significantly increased by green roofs. According to findings by [20], if PV panels are placed at a height less than 100 cm, such green roofs might be capable to minimize air temperatures in some of the tropical regions. In addition, research by [17] proved that setting up PV-green roofs with traditional black covers may reduce net sensible heat flux by approximately half. A better performance of solar PV system for a capillary irrigated, blue green roof with a bitumen roof in a moderate maritime climate is seen.

Previous studies have extensively discussed the potential of building energy consumption mitigation due to climate change; including the provision PV integrated green roofs [3, 16]). Moreover, cool (green) roofs are found to be effective in minimizing thermal effect and urban vegetation during extreme heat events in three Canadian areas [29]. Lastly, the potential mitigation impacts of green roofs integrated with solar PV systems on raised building energy demand to see which type of building can receive the maximum advantage from energy savings [3]. Urban Green Infrastructure or bio solar green roof (BSGR) system offers a vital sustainable approach that can attain climate change alteration as well as mitigation [24]. Hence, such green roofs technologies can help in achieving UN SDGs.

Spectrum of Engineering Sciences
SPECTRUM OF ENGINEERING SCIENCES
Online ISSN
3007-3138
Print ISSN
3007-312X

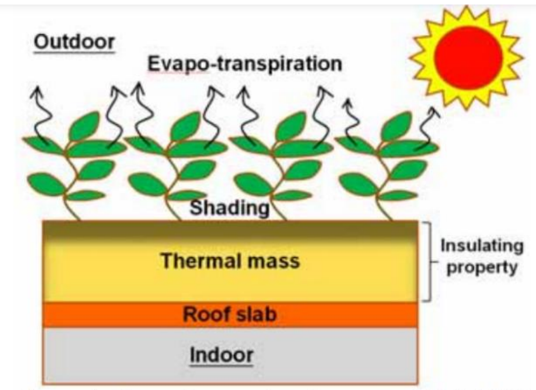

Figure 1. Thermal properties of green roof (Hui, 2009)

Fig. 1: Green roof thermal properties

The objectives of our research is to look into the possible alleviating effects of BSGR on buildings in urbanized area which are particularly susceptible to climate change because of their elevated power demands. The present research attempts to fill the knowledge gap by emphasizing the positive effects of BSGR in the context of changing climates and Urban Heat Island. It is important as global warming could lead to an abrupt rise in decreasing energy demand, especially in subtropical and tropical populations. Lastly, it explores the role of BSGR in enhancing urban resilience/sustainability via performing a literature review to address specific research problem (question) connected to resilient and sustainable societies and communities and policy recommendations.

Methodology

There are numerous types of reviews available in the published literature. Some includes critical reviews, scoping reviews, mixed studies. While other contains rapid, and systematic reviews [15]. This is a way or technique that compiles or summarizes the findings of various studies [16]. Making questions to get data, plan (develop a search strategy), search or screen (database/ literature),

Spectrum of Engineering Sciences
SPECTRUM OF ENGINEERING SCIENCES
Online ISSN
3007-3138
Print ISSN
3007-312X

manage (verify to avoid the duplication), synthesize the documents, and lastly extract results from them are part of the systematic review [17]. Systematic reviews can be done in many ways. PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) standards and Guide from AHRQ for eeffectiveness and comparative eeffectiveness reviews help writers to produce accurate systematic reviews as shown in Figure 2[18]. This includes a four-phase flow diagram to add and remove any published study from our systematic review. At first, the study checked the role of BSGR in urban environment. Then, a detailed examination of our decided framework to integrate green roofs in urbanized areas/cities was done, putting emphasized on improving urban sustainability. The review also involved the function of BSGR in climate change adaptation planning, putting light on their potential significance. During the investigation, options related to BSGR in urban contexts were noted, providing a comprehensive understanding of their numerous impacts.

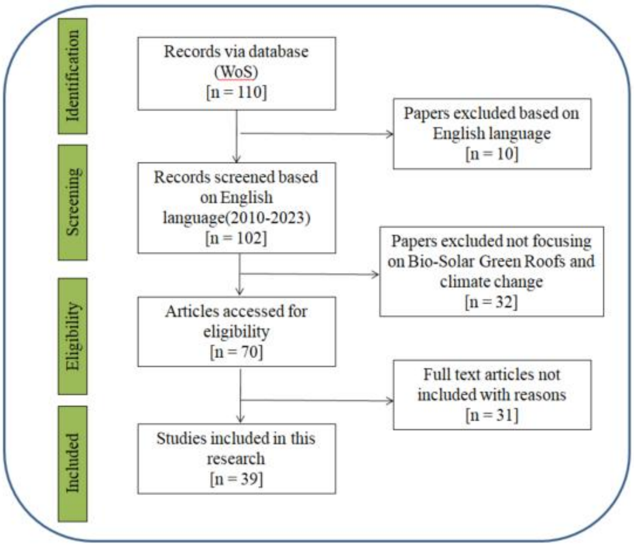

Fig. 2: PRISMA Framework for bio-solar green roofs and climate change

Spectrum of Engineering Sciences
SPECTRUM OF ENGINEERING SCIENCES
Online ISSN
3007-3138
Print ISSN
3007-312X

Data Collection

A systematic review is planned and designed to check similar studies on BSGR in the context of climate change. For sourcing published articles on BSGR and climate change, document directory (Web of Science, WoS) has served as the main database, especially in urban sustainability and planning etc. The PRISMA framework shows the steps taken, as shown in Fig. 2 below. The data was checked on Oct 20th, 2024, with the keywords "bio sola green roof*" and "climate change". We considered such keywords must be available in the title as well as in the abstract. Only journal articles available in English were considered. The initial search yielded 108 articles for recent years (2015- 2024), and later the framework was utilized for doing a systematic screening. We applied a filter in first Phase (Identification): 5 published articles were removed out by applying check like English language filters, and 3 articles were not considered as they were review papers. In second Phase (screening), 32 articles were further identified which do not considered the inclusion criteria, i.e., the keywords present in the title, and the abstract. In the 3rd phase (eligibility), remaining 70 journal articles were again checked to see if they fulfill the criteria. There we excluded articles focusing on other interventions, i.e., solar panels, parking lots using PV, green streets etc. 31 articles were removed then. In Phase 4, finally, 39 articles were chosen for the thematic and bibliometric review.

Data Analytical Methods

Bibliometric Analysis

This is a statistical way to check published literature. It uses a bibliometric methodology to generate descriptive literature. Here we used four approaches to identify trends of research. In the

Spectrum of Engineering Sciences
SPECTRUM OF ENGINEERING SCIENCES
Online ISSN
3007-3138
Print ISSN
3007-312X

beginning, a historical check for the number of published articles on BSGR and climate change each year was selected. Then, a keyword check for the authors was performed. The importance of article was checked by the citation analysis. Lastly, a country wise study was done to see which country have published articles on selected topics. Simple MS Excel, Endnote Referencing system etc, were used for generating tables, and references. Lastly, the Analyze Results feature from WoS, was used to check the reliability of our results.

Results

Bibliometric Analysis

Overview of Publication

A publication overview on BSGR and climate change under urban sustainability along with resilience etc is presented in the Table 1. One hundred and eight research papers were taken from couple of journals (30) using the chosen keywords. It is seen that the total citations of chosen journal articles are over 1582. While, an average citation per article is 14.1. The articles used a net 230 unique keywords. Also, about 277 authors with 215 institutes contributed in the published articles on BSGR, and climate change for urban sustainability, resilience and adaptation planning.

Table 1: Overview of selected papers in the Web of Science database

Serial No	Fields	Summary of publications
1	Articles	39
2	Source (journals)	30
3	Citations	1582
4	Average citation per article	14.1

Spectrum of Engineering Sciences
SPECTRUM OF ENGINEERING SCIENCES
Online ISSN
3007-3138
Print ISSN
3007-312X

5	Authors	277
6	Keywords used	230
7	Institutions	215
8	Countries	26

Number of Publications, Sources and Authors

The number of published articles each year is shown in shape of a graph with details of 39 selected research articles (Fig. 3). Nowadays, the number of published articles has increased. The reason could be the increased awareness for clean and green energies, climate change, urban sustainability resilience, and adaptations etc. Such growth is also linked with heightened hydro-meteorological extremes like floods, droughts, heat waves, and rising pollution. Such activities and emphasizes on sharing proper information and working for sustainable environments in urban hubs. The top five authors who have published articles on BSGR and climate change, in the context of urban energy saving and resilience, are illustrated in Fig. 3.

It is also noted that most of the articles, 05 in numbers were published in 2022, soon after the COVID-19 spread. It means that public and concern professionals were more favored towards neat and green solutions to achieve urban sustainability and to stand firm against expected extreme events.

Vol. 3 No. 2 (2025)

Spectrum of Engineering Sciences

SPECTRUM OF ENGINEERING SCIENCES

Online ISSN

3007-3138

Print ISSN

3007-312X

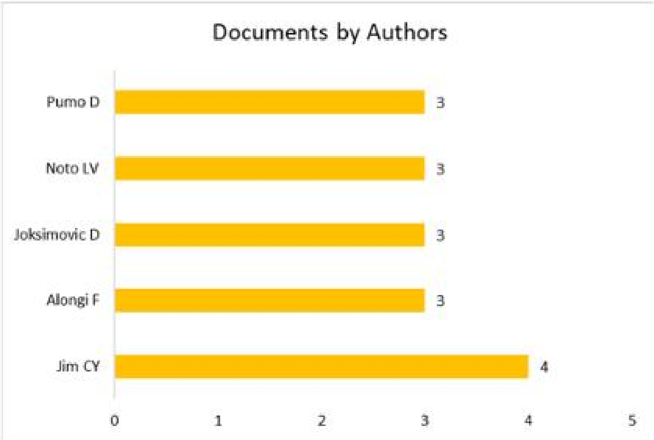

Fig. 3. Five top aauthors who published articles on BSGR and climate change

Keyword Analysis

This analysis explains the link between bio-solar green roofs, climate change, energy savings, and urban sustainability comprehensively. The downloaded papers were found to have 230 different keywords. VOS viewer was then utilised to see the potential connection as well as coexistences between the terminologies given by authors and selected papers.

Thematic Analysis

After a detailed review of the obtained articles (n=39), thematic areas along with their scopes were identified. Some papers were not published (under review), hence discarded. After seeing the article content and results with care, every chosen theme is further divided into many sub-themes considering climate change, carbon footprints, UHI, energy efficiency, flood risk management, biodiversity improvement etc (Table 2). The objective is to investigate the key mechanisms contributing towards urban resilience and sustainability via BSGR implementations. Moreover, the role of nature-based way outs, especially BSGR in the context of climate change, will be explored in a broader context of ecology

Spectrum of Engineering Sciences
SPECTRUM OF ENGINEERING SCIENCES
Online ISSN
3007-3138
Print ISSN
3007-312X

while improving potential implications to achieve urban sustainability.

Table 2: Various Themes Available in the Chosen Articles

Serial No	Themes	Sub-themes
1	Climate change (24%)	Hydrological cycles, climate extremes
2	Urban Heat Islands (20.5%)	Green infrastructure (extensive and intensive green roofs)
3	Carbon footprint reduction (15.5 %)	Life cycle CO^2 emissions
4	Flood risk management (11%)	Drinking water, water quality, sedimentation Flood risk reduction
5	Energy efficiency (14%)	Efficiency, energy losses, line losses.
6	Human Well-being (15%)	Mindful engagement Improved air quality Noise, comfortable temperature

Spectrum of Engineering Sciences
SPECTRUM OF ENGINEERING SCIENCES
Online ISSN
3007-3138
Print ISSN
3007-312X

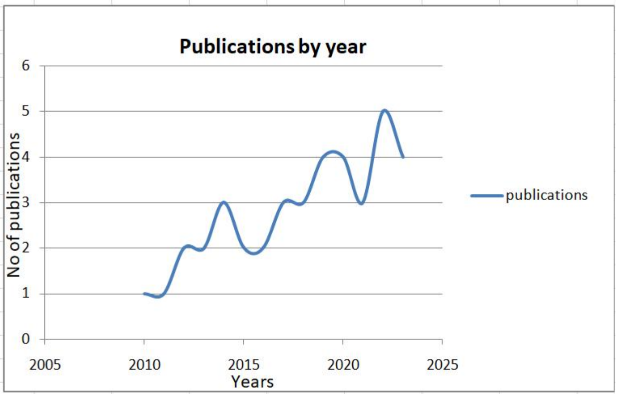

Fig. 4: Yearly publications on bio solar green roofs and chosen keywords (Checked on 20th October 2024)

Urban Heat Island

UHI issues are available in cities due to different reasons. It includes decrease in natural areas, low ability to reflect in the structures, urban morphology, streets layout, and human-produced warmth. Moreover, the difference in temperature in urban and rural areas is sometimes resembled as a standard to show UHIs. More absorption from urban surfaces, i.e., from roofs, and pavements, against surfaces with vegetation, causes in a UHI increase. The hottest days or times are when the UHI surface is at the maximum. BSGR can potentially limit urban heat levels to a significant level efficiently. However, many factors are included to make a reasonable impact on regional or local environment (temperature) [21]. Green roofs with different plant species has a positive impact in lowering the nearby temperature compared to green roofs with similar species of plants. Their size, roof arrangement etc also play an important role in minimizing UHI stresses [21]. Such integrating in urban areas can possibly minimize the heat-related death rate in hot days [22]. Also, during days with heat, BSGR can minimize the surface temperature and flow of heat to 80 % through roof surface [23]. A research

Spectrum of Engineering Sciences
Online ISSN
3007-3138
Print ISSN
3007-312X
SPECTRUM OF ENGINEERING SCIENCES

performed in Italy presents that 12°C surface temperatures is lowered owing to BSGR [25]. Similarly, [28] found out that the average temperature on cities rooftop could be minimized by 0.3–3.0 deg-Celsius.

Relevant studies have demonstrated that BSGR reduces the UHI effect exponentially and raise their reflectance [30]. Albedo of the BSGR also varies from 0.7-0.85, compared to conventional roof (>1.2) with tar, and concrete [31]. Most roofs with green covers in shape of plants have shown benefits, like UHI mitigation, improving air quality [22,32], and better biodiversity [33]. The green building trend is also increasing among town-planners, and policymakers, showing a shift in policy in the coming years. Such shifts are very much supportive and kind of good signs regarding sustainable and resilient communities, green infrastructure and managing natural resources well.

Climate Impacts by Lowering Carbon Footprints

Bio Solar Green roofs provide a viable option for cities with raised temperatures to improve the natural environment, hence substantial potential to reduce the buildings carbon footprints [34]. Many researchers have encouraged using sustainable or recycled materials during the production to reduce carbon footprints [35, 36].

Energy Consumption

Despite BSGR benefits in minimizing energy consumption along with improving ecology. Further studies used latest tools to lower carbon footprint and energy usage during the construction, implementation etc [37, 38, 39]. Some studies assess the environmental impact of newly constructed buildings those made up of vegetable rooftop (waste from a tomato crop) [40].

Spectrum of Engineering Sciences
SPECTRUM OF ENGINEERING SCIENCES
Online ISSN
3007-3138
Print ISSN
3007-312X

Supporting BSGR applications considering the larger public benefit and their interest will be a good strategy to have a sustainable environment by minimizing energy consumption causing elevated temperature [41, 42] owing to fossil fuel emissions [43, 44].

Conclusion

Bio Solar Green Roofs can deal with climate change by minimizing carbon, lowering UHI effects, and improving efficiency of energy system through improved insulation. They help in climate adaptation by managing flows, improving quality of air, and levels of thermal comfort. Since they are multipurpose, hence suitable for moderate climates, heat waves, and regions with problems related to air quality. Future research may consider on longer-term check of BSGR to better comprehend how they behave over time or with varying weather anomalies especially in urban hubs. On the other hand, there is an issue like public awareness that stops green roof adaptation and acceptability. Some of those can be identified as low efficiencies by solar cell, high costs, less availability and very less knowledge to general public regarding such green energy interventions.

The main findings of our study are:

Components of BSGR are chosen based on structural strengths etc and aesthetics. Benefits like better air quality and limiting noise etc were not researched much.

BSGR are expensive to install though, but after some time they payback the costs involved BSGR offers led installation, maintenance and similar costs compared to normal or conventional electricity production household systems.

Despite its various benefits, like improved thermal comfort, maintenance is expensive compared to conventional concrete or

Spectrum of Engineering Sciences
SPECTRUM OF ENGINEERING SCIENCES
Online ISSN
3007-3138
Print ISSN
3007-312X

bituminous roofs. The lack of skilled labour availability locally adds to the challenge.

Future research perceptions could rely on the flora and fauna types of green roofs and to design them in a better way to improve biodiversity and efficiency.

Public perception of BSGR roofs can impact their adoption and input to the system successfully in urbanized areas. More research may focus on seeing how different components of the publicly available BSGRs and better designing that are more appealing visually and acceptable socially as well.

By mitigating UHIs, reducing storm water runoff, conserving our biodiversity, and limiting carbon, BSGR serve as a natural solution that advances urban environmental sustainability. They help minimizing the undesirable effects of climate change by improving quality of air and water.

BSGR also supports ecological resilience, thereby creating more healthier and sustainable ecosystems in urban places.

References

[1] Arias, P. A., Bellouin, N., Coppola, E., et al: Technical summary, 2021.

[2] Noto, L. V., Cipolla, G., Pumo, D., et al.: Climate change in the Mediterranean Basin (Part II): a review of challenges and uncertainties in climate change modeling and impact analyses. Water Resources Management, 2023, 37(6), 2307-2323.

[3] Zheng, Y., & Weng, Q.: Modeling the effect of green roof systems and photovoltaic panels for building energy savings to mitigate climate change. Remote Sensing, 2020, 12(15), 2402.

Spectrum of Engineering Sciences
SPECTRUM OF ENGINEERING SCIENCES
Online ISSN
3007-3138
Print ISSN
3007-312X

[4] Huang, J., & Gurney, K. R.: The variation of climate change impact on building energy consumption to building type and spatiotemporal scale. Energy, 2016, 111, 137-153.

[5] Ali, M., Kim, H.: Global assessment for reduction of solar photovoltaic potential due to meteorological and geomorphological limiting factors. In EGU General Assembly Conference Abstracts, 2021, pp. EGU21-5773.

[6] Zhou, Q., Hanasaki, N., & Fujimori, S.: Economic consequences of cooling water insufficiency in the thermal power sector under climate change scenarios. Energies, 2018, 11(10), 2686.

[7] IPCC 2013. Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK.

[8] Nguyen, D. T., Ashraf, S., Le, M., et al.: Projection of climate variables by general circulation and deep learning model for Lahore, Pakistan. Ecological Informatics, 2023, 75, 102077.

[9] Ahmad, I., Zhang, F., Tayyab, M., et al.: Spatiotemporal analysis of precipitation variability in annual, seasonal and extreme values over upper Indus River basin. Atmospheric Research, 2018, 213, 346-360.

[10] Khattak, M. S., Babel, M. S., & Sharif, M.: Hydro-meteorological trends in the upper Indus River basin in Pakistan. Climate research, 2021, 46(2), 103-119.

[11] Serencam, U.: Innovative trend analysis of total annual rainfall and temperature variability case study: Yesilirmak region, Turkey. Arabian Journal of Geosciences, 2019, 12(23), 704.

[12] Lopez, B., Baran, N., & Bourgine, B.: An innovative procedure to assess multi-scale temporal trends in groundwater quality:

Spectrum of Engineering Sciences
SPECTRUM OF ENGINEERING SCIENCES
Online ISSN
3007-3138
Print ISSN
3007-312X

Example of the nitrate in the Seine–Normandy basin, France. Journal of Hydrology, 2015, 522, 1-10.

[13] Dimond, K., & Webb,: A. Sustainable roof selection: Environmental and contextual factors to be considered in choosing a vegetated roof or rooftop solar photovoltaic system. Sustainable cities and society, 2017, 35, 241-249.

[14] Elhabodi, T. S., Yang, S., Parker, J., et al.: A review on BIPV-induced temperature effects on urban heat islands. Urban Climate, 2023, 50, 101592.

[15] Bamdad, K.: Cool roofs: A climate change mitigation and adaptation strategy for residential buildings. Building and Environment, 2023, 236, 110271.

[16] Shafique, M., Kim, R., & Rafiq, M.: Green roof benefits, opportunities and challenges–A review. Renewable and Sustainable Energy Reviews, 2018, 90, 757-773.

[17] Li, X., & Ratti, C.: Mapping the spatial distribution of shade provision of street trees in Boston using Google Street View panoramas. Urban Forestry & Urban Greening, 2018, 31, 109-119.

[18] Wang, Y., Akbari, H., & Chen, B.: Urban geometry and environmental urban policy development. Procedia Engineering, 2016, 169, 308-315.

[19] Alcazar, S. S., Olivieri, F., & Neila, J.: Green roofs: Experimental and analytical study of its potential for urban microclimate regulation in Mediterranean–continental climates. Urban Climate, 2016, 17, 304-317.

[20] Morakinyo, T. E., Dahanayake, K. K. C., Ng, E., et al.: Temperature and cooling demand reduction by green-roof types in different climates and urban densities: A co-

Spectrum of Engineering Sciences
SPECTRUM OF ENGINEERING SCIENCES
Online ISSN
3007-3138
Print ISSN
3007-312X

simulation parametric study. Energy and Buildings, 2017, 145, 226-237.

[21] Herrera-Gomez, S. S., Quevedo-Nolasco, A., & Pérez-Urrestarazu, L.: The role of green roofs in climate change mitigation. A case study in Seville (Spain). Building and Environment, 2017, 123, 575-584.

[22] Singh, R., & Banerjee, R.: Estimation of rooftop solar photovoltaic potential of a city. Solar Energy, 2015, 115, 589-602.

[23] Sailor, D. J., Elley, T. B., & Gibson, M.: Exploring the building energy impacts of green roof design decisions–a modeling study of buildings in four distinct climates. Journal of Building Physics, 2012, 35(4), 372-391.

[24] Jia, S., Wang, Y., Wong, N. H., Tan, C. L., et al.: Estimation of mean radiant temperature across diverse outdoor spaces: A comparative study of different modeling approaches. Energy and Buildings, 2024, 310, 114068.

[25] Heusinger, J., Sailor, D. J., & Weber, S.: Modeling the reduction of urban excess heat by green roofs with respect to different irrigation scenarios. Building and Environment, 2018, 131, 174-183.

[26] Ramshani, M., Khojandi, A., Li, X., & Omitaomu, O.: Optimal planning of the joint placement of photovoltaic panels and green roofs under climate change uncertainty. Omega, 2020, 90, 101986.

[27] Jahanfar, A., Drake, J., Gharabaghi, B., et al.: An experimental and modeling study of evapotranspiration from integrated green roof photovoltaic systems. Ecological Engineering, 2020, 152, 105767.

Spectrum of Engineering Sciences
SPECTRUM OF ENGINEERING SCIENCES
Online ISSN
3007-3138
Print ISSN
3007-312X

[28] Liu, H. Y., kandalos, N., Braslina, L., et al.: Integrating solar energy and nature-based solutions for climate-neutral urban environments. In Solar, 2023, Vol. 3, 3, pp. 382-415.

[29] Schindler, B. Y., Blaustein, L., Lotan, R., et al.: Green roof and photovoltaic panel integration: Effects on plant and arthropod diversity and electricity production. Journal of environmental management, 2018, 225, 288-299.

[30] Chemisana, D., & Lamnatou, C.: Photovoltaic-green roofs: An experimental evaluation of system performance. Applied Energy, 2014, 119, 246-256.

[31] Berardi, U., Ghaffarian Hoseini, A., & GhaffarianHoseini, A.: State-of-the-art analysis of the environmental benefits of green roofs. Applied energy, 2014, 115, 411-428.

[32] Wang, Y., Berardi, U., & Akbari, H.: Comparing the effects of urban heat island mitigation strategies for Toronto, Canada. Energy and buildings, 2016, 114, 2-19.

[33] Aleksejeva, J., Voulgaris, G., & Gasparatos, A.: Assessing the potential of strategic green roof implementation for green infrastructure: Insights from Sumida ward, Tokyo. Urban Forestry & Urban Greening, 2022, 74, 127632.

[34] Nadeeshani, M., Ramachandra, T., Gunatilake, S., & Zainudeen, N.: Carbon footprint of green roofing: a case study from Sri Lankan construction industry. Sustainability, 2021, 13(12), 6745.

[35] Grigoletti, G. D. C., & Pereira, M. F. B.: Carbon dioxide emissions of green roofing–case study in southern Brazil. In 30th International Plea Conference, 2014, pp. 1-8.

[36] Tams, L., Nehls, T., & Calheiros, C. S. C.: Rethinking green roofs-natural and recycled materials improve their carbon

Spectrum of Engineering Sciences
Online ISSN
3007-3138
Print ISSN
3007-312X
SPECTRUM OF ENGINEERING SCIENCES

footprint. Building and Environment, 2022, 219, 109122.
[37] Cai, L., Feng, X. P., Yu, J. Y., et al.: Reduction in carbon dioxide emission and energy savings obtained by using a green roof. Aerosol and Air Quality Research, 2019, 19(11), 2432-2445.
[38] Ali, M., & Kim, H.: Global assessment for reduction of solar photovoltaic potential due to meteorological and geomorphological limiting factors. In EGU General Assembly Conference Abstracts, 2021, pp. EGU21-5773.
[39] Kim, H., & Ali, M.: Global Assessment of Photovoltaic Resource and Interaction with Climate System. Korean Solar Energy Society Conference Proceedings , 2021, 141-141.
[40] Llorach-Massana, P., Cirrincione, L., Sierra-Perez, J., et al.: Environmental assessment of a new building envelope material derived from urban agriculture wastes: the case of the tomato plants stems. The International Journal of Life Cycle Assessment, 2023, 28(7), 813-827.
[41] Rahman, M. A., Ali, M., Mojid, M. A., et al.: Crop coefficient, reference crop evapotranspiration and water demand of dry-season Boro rice as affected by climate variability: A case study from northeast Bangladesh. Irrigation and Drainage, 2023, 72(1), 148-165.
[42] Ali, M., Gillani, S. H., & Ali, U.: Flash Drought Monitoring in Pakistan Using Machine Learning Techniques and Multivariate Drought Indices. Technical Journal, 3(ICACEE), 2024, 717-729.
[43] Ali, M., Taha, M., Aziz, M. S., Ahmed, H., et al.: Flash Flood prediction of Panjkora River, KPK, Using Artificial Neural Networks (ANN) and Support Vector Machine (SVM). Technical Journal, 3(ICACEE), 2024, 758-769.

Spectrum of Engineering Sciences
Online ISSN
3007-3138
Print ISSN
3007-312X
SPECTRUM OF ENGINEERING SCIENCES

[44] Ali, M., Ali, U., & Gillani, S. H. FLASH DROUGHT DETECTION AND RISK EXPOSURE IN PAKISTAN: A MACHINE LEARNING APPROACH WITH MULTIVARIATE INDICES. 9th Multi Disciplinary Student Research International Conference (MDSRIC). 16-17th October 2024 (MDSRIC), University of Wah, 2024.