

# The Contribution of Green Roofs in the Achievement of Sustainable Development Goals

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**ABSTRACT:** Green roofs are eco-friendly systems designed to deliver environmental, economic and social benefits while they enhance the aesthetic appeal of buildings. Their construction on rooftop of buildings in urban communities is important for the local residents and the environment. The Sustainable Development Goals are a set of 17 global objectives established by the United Nations in 2015 serving as a blueprint for developing a more sustainable, equitable and prosperous world by 2030, focusing on environmental, economic and social progress. The multiple benefits of green roofs are related with the achievement of the sustainable development goals. Creation of green roofs in urban areas facilitates the achievement of the SDG3 related with good health and well-being as well as SDG11 related with sustainable cities and communities, SDG13 related with climate action and SDG15 related with life on land. Therefore, the development of green roofs in urban areas is very useful and beneficial for the buildings' residents, the environment and the local community. Due to multiple external benefits of green roofs their construction should be promoted with financial and non-financial incentives by municipal and regional authorities combined with removal of several barriers hindering their adoption and development.

**KEYWORDS:** Benefits, green roofs, cities' resilience, urban development, sustainable development goals, synergies

## 1. INTRODUCTION

The construction of green roofs on rooftop of buildings in urban areas is increasing due to their multiple benefits. These benefits include their positive role in the achievement of the Sustainable Development Goals (SDGs) of United Nations (UN). Several researchers have analyzed the contribution of green roofs in the achievement of the SDGs [1], [2], [3], [4]. Many studies indicate the environmental, economic and social benefits of green roofs [5], [6]. Green roofs contribute to climate change mitigation which is linked with the achievement of the SDGs [7]. Construction of green roofs on rooftop of buildings results to atmospheric CO<sub>2</sub> sequestration of and to decrease of CO<sub>2</sub> emissions due to reduction of energy consumption in buildings [8], [9]. Other benefits of green roofs include the mitigation of UHI effect [10], the removal of various atmospheric pollutants including CO<sub>2</sub> [9], [11] the possibility of developing urban agriculture [12], [13] the better management of rainwater, the decrease of energy consumption in buildings [14] the promotion of biodiversity in urban areas [15] the promotion of ecological balance, the well-being and the stress relief in the neighborhood and the improvement of buildings' aesthetic.

*The aim of our research is to study the contribution of green roofs in the achievement of the Sustainable Development Goals of United Nations.*

The text is structured as follows: after the literature survey the SDGs of UN are described. In the next two sections the green

roofs and their multiple benefits are analyzed. After that the contribution of green roofs in the achievement of the SDGs is stated followed by discussion of the findings, the conclusions drawn and the citation of the references used. Our study fills the gap related with the linkage of green roofs with the SDGs and it is innovative due to lack of similar studies. The results could be useful to policy makers, to local authorities as well as to architects and urban developers.

## 2. LITERATURE SURVEY

The contribution of a university's green roof to sustainable development has been studied [1]. The authors stated that green infrastructure including green roofs contribute to several SDGs such as SDG 3 (good health and wellbeing), SDG 10 (reduced inequalities), SDG 11 (sustainable cities and communities), SDG 13 (climate action), and SDG 15 (life on land). The life cycle assessment of green roofs has been studied [2]. The authors stated that green roofs provide several environmental, economic and social benefits promoting the achievement of SDGs. The use of green roofs as a means of sustainable urban development has been analyzed [3]. The authors stated that green roofs can contribute towards the achievement of multiple SDGs. They also mentioned that green roofs can also contribute towards the achievement of 12 out of 17 SDGs. The green roofs as a solution to sustainable development of urban areas have been studied [5]. The authors analyzed the benefits of green roofs

on the building, the city and the society. The contribution of green roofs in the achievement of circular and resilient cities has been examined [16]. The authors stated that green roofs are a nature-based solution in cities providing several ecosystem services while they play a pivotal role in the water-energy-materials-food ecosystems nexus. A report related with the living architecture in Australia has been published [6]. The report stated that resilience in cities can be promoted with the construction of green roofs having social, economic and environmental benefits. It is also mentioned that several barriers related with the promotion of green roofs exist such as: the construction and maintenance cost, lack of awareness and lack of professional guidance. A report related with the necessity to promote climate change mitigation and the achievement of SDGs in cities has been published [7]. The report stated that climate change mitigation and achievement of SDGs in cities require policies that leverage the synergies between them. The social impacts of green roofs have been studied [8]. The authors stated that green roofs account for 20-25% of all urban area. They also mentioned that green roofs decrease the energy consumption in buildings offering social and ecological benefits in urban communities. A report examining the synergies between climate change mitigation and the achievement of SDGs has been published [17]. It is stated that tackling together climate change and SDGs is the only way to promote sustainable development. It is also mentioned that the goals of Paris 2015 and the SDGs cannot be achieved separately. The state-of-art of green roofs has been reviewed [18]. The authors stated that green roofs are necessary in alleviating the adverse effects of urban population growth. They also mentioned that the increased interest of green roofs reflects the commitment to address the challenges of urbanization through sustainable practices. A report regarding the implementation of the United Nations' sustainable development goals in the city of Mannheim, Germany has been published [19]. The report stated that Mannheim is focusing on the following goals: a) Equality, b) integration and biodiversity, c) environmental sustainability, d) increased tolerance, and e) child development. The techniques of green roofs in Taif city, Saudi Arabia have been studied [4]. The authors stated that green roof technology can help in the achievement of several SDGs. They also mentioned that green roofs can increase the sustainability of buildings achieving better rating. The linkages between climate change policies and the achievement of the SDGs have been analyzed [20]. The authors stated that there are more synergies than trade-offs between climate change policies and the achievement of SDGs in all world regions. They also mentioned that increasing the share of renewable energies in power generation shows higher synergies with the other SDGs. Six transformations to achieve the SDGs have been examined [21]. The authors proposed the following six transformations which improve the achievement of the SDGs. These are: a) education, gender and inequality, b) health,

well-being and demography, c) energy decarbonization and sustainable industry, d) sustainable food, land, water and oceans, e) sustainable cities and communities, and f) digital revolution and sustainable development. The millennium development goals (MDGs) and the SDGs. have been studied [22]. The author stated that many countries have made considerable progress in achieving the SDGs. He also mentioned that SDGs follow a triple bottom line approach to human well-being including economic development, environmental sustainability and social inclusion. A report regarding the challenges and opportunities in the implementation of 17 SDGs has been published [23]. The authors identified six critical areas which are important for achieving all the SDGs. These six megatrends are related with: a) poverty and inequalities, b) demography, c) environmental degradation and climate change, d) shocks and crisis, e) cooperation and financing for development, and f) technological innovation. The implementation of the SDGs has been examined [24]. The authors stated that there must be greater attention on interlinkages in three areas: a) across sectors (finance, agriculture, energy et cetera), b) across societal actors (local authorities, government agencies, private sector and civil society), and c) between and among low, medium and high-income countries. The strategies for the achievement of SDGs have been analyzed [25]. The authors investigated which pillars of SDGs (economic, social and environment) are the most effective in achieving sustainable development. They stated that developed countries benefit most by focusing in social and environmental factors while the developing countries in economic and social factors. The universal SDGs have been analyzed [26]. The authors stated that the goals and targets represent different degrees of challenge for different countries depending on the present state of development and other national circumstances. The balance between the social, economic and political effort needed to deliver the different objectives is also likely to be different in different countries. A framework for the SDGs has been examined [27]. The authors stated that humanity's impact on Earth's life support system is so great that further environmental change risks undermine long-term prosperity and poverty eradication goals. They also mentioned that socio-economic development and global sustainability are often posed as being in conflict. The role of financial inclusion in achieving the SDGs has been analyzed [28]. They stated that there is a clear link between financial inclusion and development while the governments should continue to push for greater access to and use of financial services. They also mentioned that prioritizing financial services does not take away resources from other key priorities set through the SDGs. An overarching goal for the UN SDGs has been developed [29]. The authors stated that SDGs may have three levels of hierarchy as follows: a) the lower level is characterized by staying within planetary boundaries, b) the middle level is

characterized with building a living economy for protecting the capabilities for flourishing, and c) the top level includes the overarching goal for a prosperous, high quality of life that is equitably shared and sustainable. The carbon removal from green roofs in urban communities focusing in the city of Chania, Crete, Greece has been evaluated [11]. The author estimated that coverage of 5% of buildings' rooftops, in the municipal unit of Chania with green roofs, in an area at 400,000 m<sup>2</sup>, 880 tCO<sub>2</sub>/year will be removed from the atmosphere due to plants' photosynthesis and 4,400 tCO<sub>2</sub>/year will not be emitted due to lower energy consumption in buildings. Additionally, he mentioned that the construction cost of green roofs is at around 13.2 mil. €. The benefits of green roofs have been reviewed [30]. The authors stated that green roofs have many environmental, economic, energy and social benefits. Their construction on rooftops of buildings facilitates cities and communities to be more sustainable increasing the well-being of the local inhabitants. The role of green roofs in decreasing atmospheric pollution has been investigated [9]. The authors stated that green roofs reduce air pollution by removing several pollutants such as NO<sub>x</sub>, O<sub>3</sub>, particulate material et cetera. Additionally, they remove atmospheric CO<sub>2</sub> by plants' photosynthesis and reduce CO<sub>2</sub> emissions due to decrease of energy consumption in buildings. The promotion of biodiversity with green roofs in Sydney, Australia has been studied [15]. The authors compared the biodiversity in similar buildings with and without green roofs. Their experimental results indicated that green roofs became habitat for local fauna. They stated that green roofs are ecologically significant attracting and supporting local fauna. The food production in buildings has been studied [13]. The authors stated that urban agriculture has many environmental, economic and social benefits. They also mentioned that urban agriculture on rooftop of buildings has some potential in generating win-win scenarios in cities. The impacts of green roofs in urban areas have been analyzed [12]. The authors stated that green roofs can provide food in urban communities produced in spaces that are unused. They also mentioned that rooftop agriculture can improve various ecosystem services, enrich urban biodiversity and reduce food insecurity. The impacts of green roofs on energy demand for cooling in Egyptian buildings have been examined [14]. The authors stated that the proposed green roof reduces the energy consumption in the building by 31.61% to 39.74%. They also mentioned that green roofs in hot arid areas reduce the air temperature by around 4°C. The mitigation of the UHI effect with green roofs in urban areas has been studied [10]. The author stated that preserving biodiversity is very important in cities which are expanding. He also mentioned that green roofs mitigate the UHI effect while they offer the opportunity for urban farming. The production of green water from green roofs and its ecological and economic impacts with reference cities in Poland with population greater than 250,000 inhabitants has been studied [31]. The authors stated

that intensive green roofs are more profitable than extensive green roofs while their Net Present Value was estimated at 60.77 \$/year and 4.47 \$/year correspondingly. The impact of green roofs on the mitigation of UHI effect has been studied [32]. The authors stated, that according to their experimental data, the indoor temperature in buildings with green roofs is reduced by 2.4°C compared to outdoor temperature while in buildings without green roofs the indoor temperature is lower at 0.8°C compared to the outdoor. The use of moss for urban green roof applications has been investigated [33]. The authors estimated the carbon sequestration from the moss planted in green roofs stating that it varies between 1.22 kgCO<sub>2</sub>/m<sup>2</sup>/year and 2.66 kgCO<sub>2</sub>/m<sup>2</sup>/year.

### 3. THE SUSTAINABLE DEVELOPMENT GOALS

The Sustainable Development Goals (SDGs) are a set of 17 global objectives established by the United Nations in 2015. They aim to address the most pressing challenges facing the world, such as poverty, inequality, environmental degradation, and climate change. The SDGs serve as a blueprint for creating a more sustainable, equitable, and prosperous world by 2030, emphasizing the interconnectedness of social, economic, and environmental progress. One of the central goals is the eradication of poverty (Goal 1), as poverty remains one of the greatest barriers to sustainable development. Similarly, the SDGs target zero hunger (Goal 2) and quality education (Goal 4), aiming to ensure that all people have access to basic necessities and opportunities for growth. These goals reflect the belief that no one should be left behind in the pursuit of prosperity. Environmental sustainability is also a core focus of the SDGs. Climate action (Goal 13) calls for urgent efforts to combat climate change and its impacts, while goals such as clean water and sanitation (Goal 6), affordable and clean energy (Goal 7), and life below water and on land (Goals 14 and 15) emphasize the need to protect and preserve natural resources. Economic growth and innovation are encouraged through goals like decent work and economic growth (Goal 8) and industry, innovation, and infrastructure (Goal 9). These aim to create sustainable economies that provide opportunities for all while reducing environmental harm. The SDGs recognize that global cooperation is essential for success. Partnerships for the goals (Goal 17) emphasizes collaboration between governments, businesses, and civil society to achieve these ambitious targets. Therefore, the SDGs represent a comprehensive strategy for addressing global challenges and creating a future where all people can thrive in harmony with the planet. Their implementation is essential for ensuring long-term prosperity and environmental sustainability for generations to come. The 17 sustainable development goals are presented in table 1.

**Table 1. The 17 Sustainable Development Goals of United Nations**

SDG	Title
1	No poverty
2	Zero hunger
3	Good health and well-being
4	Quality education
5	Gender equality
6	Clean water and sanitation
7	Affordable and clean energy
8	Decent work and economic growth
9	Industry, innovation and infrastructure
10	Required inequalities
11	Sustainable cities and communities
12	Responsible consumption and production
13	Climate action
14	Life below water
15	Life on land
16	Peace, justice and strong institutions
17	Partnership for the goals

Source: Balabel et al, 2024

#### 4. GREEN ROOFS

Green roofs are rooftops covered with vegetation, offering a blend of nature and technology in urban spaces. Unlike traditional roofs, which are often made of concrete, green roofs consist of layers that support the growth of plants. These eco-friendly systems are designed to deliver environmental, economic, and social benefits while enhancing the aesthetic appeal of buildings. A typical green roof is composed of several key layers. At the bottom is a waterproof membrane that protects the building from water damage. Above that, a root barrier prevents plant roots from penetrating the building structure. A drainage layer allows excess water to escape, preventing waterlogging. Next is a growing medium, usually soil or a lightweight substrate, which provides the nutrients needed for plant growth. Finally, the top layer consists of vegetation, which can range from simple grasses and sedums to more complex plant communities, depending on the type of green roof.

Green roofs can be classified into two main types: extensive and intensive. Extensive green roofs are lightweight, low-maintenance systems with shallow soil layers, typically supporting drought-resistant plants like mosses, herbs, and sedums. They are ideal for buildings that cannot support much weight and require minimal upkeep. In contrast, intensive green roofs have deeper soil layers and can support a wider variety of plants, including shrubs, trees, and even small urban farms. These roofs are heavier and require more maintenance but offer more design flexibility and can serve as recreational spaces. Therefore, green roofs are innovative systems that combine natural elements with modern technology to improve the sustainability of urban environments. Their unique structure and versatile plant

options make them an effective solution for enhancing city landscapes and promoting environmental well-being.

#### 5. THE BENEFITS OF GREEN ROOFS

Green roofs offer a range of environmental, economic, and social benefits. As urban areas face growing challenges such as air pollution, rising temperatures, and limited green space, green roofs are emerging as a sustainable solution to help mitigate these issues while enhancing urban living. One of the primary environmental benefits of green roofs is their role in reducing the urban heat island effect. In cities, traditional rooftops absorb and retain heat, leading to higher temperatures. Green roofs, with their vegetation cover, absorb less heat and cool the surrounding air, lowering the overall temperature in urban areas. Additionally, they improve air quality by filtering pollutants and capturing carbon dioxide, contributing to a cleaner atmosphere. They also create habitats for biodiversity, supporting wildlife even in densely populated cities. Another significant benefit of green roofs is stormwater management. In cities, rainwater typically runs off impermeable surfaces, leading to flooding and overloading drainage systems. Green roofs absorb a large portion of rainfall, reducing runoff and the risk of flooding. The plants and soil on green roofs act as natural filters, improving the quality of water that reenters the environment. From an economic perspective, green roofs can provide long-term financial savings. The additional insulation they offer reduces the energy required to heat and cool buildings, lowering energy bills. Moreover, green roofs protect the underlying roof materials from weather-related wear and tear, extending the roof’s lifespan and reducing maintenance costs. Socially, green roofs enhance the quality of urban life by creating new green spaces in crowded cities. They offer aesthetic and recreational value, providing spaces for relaxation and gardening. These green spaces can improve mental health, promote biodiversity, and foster community interaction. Therefore, green roofs offer numerous benefits by addressing environmental challenges, reducing energy costs, and improving urban well-being. As cities become more congested, green roofs are a practical and sustainable solution for creating healthier, more resilient urban environments. The multiple benefits of green roofs are presented in table 2.

**Table 2. Multiple benefits of green roofs**

Environmental	Removal of atmospheric CO <sub>2</sub>
	Removal of various atmospheric pollutants
	Release of oxygen
	Mitigation of the urban heat island effect
	Reduction of the noise in the building
	Improvement of the management of water runoff

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	Creation of a healthy ecosystem attracting birds, insects et cetera increasing the biodiversity in urban areas
Economic	Increase of the life span of the building roof
	Increase of the value of the property
	Creation of the opportunity for cultivation of vegetables and production of honey resulting in an economic benefit
	Reduction of the energy consumption and the energy bill in the building
Energy	Reduction of the heat and cooling requirements in the building
Social	Offering the opportunity for gardening and relaxation
	Improvement of the mental health and stress relief
	Promotion of ecological balance and bringing nature closer to urban residents

Source: Vourdoubas, 2024

### The contribution of green roofs in the achievement of the sustainable development goals

Green roofs are innovative solutions that can play a significant role in achieving several of the United Nations' Sustainable Development Goals. By integrating vegetation into urban rooftops, green roofs offer environmental, economic, and social benefits that align with many of the SDGs, promoting sustainability and resilience in cities. One key contribution of green roofs is Goal 11: Sustainable Cities and Communities. As urban areas continue to expand, green roofs help mitigate the urban heat island effect, lower city temperatures, and improve air quality. By creating green spaces in densely built environments, they make cities more livable and reduce pollution, contributing to healthier communities. Green roofs also enhance resilience to climate change impacts, such as increased rainfall and flooding, by absorbing stormwater, which aligns with Goal 13: Climate Action. In terms of environmental sustainability, green roofs directly support Goal 15: Life on Land, as they create urban habitats for plants, birds, and insects, fostering biodiversity even in highly developed areas. Additionally, by filtering rainwater and reducing runoff, they protect natural waterways from pollution, contributing to Goal 6: Clean Water and Sanitation. Green roofs can also contribute to Goal 7: Affordable and Clean Energy by improving energy efficiency in buildings. The vegetation on green roofs acts as insulation, reducing the need for heating in winter and cooling in summer. This results in lower energy consumption, which

supports both climate action and the transition to sustainable energy systems. Socially, green roofs offer recreational and aesthetic value, which promotes well-being and aligns with Goal 3: Good Health and Well-Being. These spaces can provide urban residents with places to relax and connect with nature, improving mental health and fostering community cohesion. Therefore, green roofs contribute significantly to the achievement of multiple SDGs by promoting environmental sustainability, enhancing urban resilience, and improving quality of life in cities. They represent an essential strategy for creating sustainable, green urban spaces. The contribution of green roofs in the achievement of the SDGs is according to different authors presented in tables 3 and 4.

**Table 3. Contribution of green roofs in the achievement of 7 sustainable development goals**

SDG	Description of the goal	Impact of green roofs
3	Good health and well-being	Green roofs can improve people's health and well-being
8	Decent work and economic growth	Green roofs increase investments, employability and incomes
9	Industry, innovation and infrastructure	Green roofs promote innovation and contribute to climate resilient infrastructure
11	Sustainable cities and communities	Green roofs are the fabric of sustainable communities and cities
12	Responsible consumption and production	Green roofs use the principles of circular economy where resources are not wasted
13	Climate action	Green roofs sequester atmospheric CO <sub>2</sub> and decrease the energy consumption in buildings reducing carbon emissions
15	Life on land	Green roofs improve biodiversity, save water and remove atmospheric pollutants

Source: Balabel et al, 2024

**Table 4. Contribution of green roofs in the achievement of 5 sustainable development goals**

SDG	Description of the goal	Impact of green roofs
3	Good health and well-being	Green roofs can improve people's health and well-being

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10	Reduced inequalities	Green roofs increase the social well-being
11	Sustainable cities and communities	Green roofs are the fabric of sustainable communities and cities
13	Climate action	Green roofs sequester atmospheric CO <sub>2</sub> and decrease the energy consumption in buildings reducing carbon emissions
15	Life on land	Green roofs improve biodiversity, save water and remove atmospheric pollutants

*Source: Nguyen Dang et al, 2023*

### 6. DISCUSSION

Construction of green roofs on rooftop of buildings in urban areas has multiple environmental, economic and social benefits. They also indirectly support the achievements of UN SDGs. Several studies regarding green roofs have indicated their positive impact in achieving some SDGs. The achievement of SDG 13 regarding climate action, of SDG 3 regarding good health and well-being, of SDG 11 regarding sustainable cities and communities, and of SDG 15 regarding life on land is facilitated with construction of green roofs on rooftop of buildings.

Currently, the most pressing challenges facing the world are poverty, inequality, environmental degradation, and climate change which can be mitigated with green roofs. The SDGs serve as a blueprint for creating a more sustainable, equitable, and prosperous world by 2030, emphasizing the interconnectedness of social, economic, and environmental progress. Several alternative energy sources and benign energy technologies such as semi-transparent solar-PVs, double face solar-PVs, heat pumps with very high efficiency, energy efficient bulbs, heat recovery from fridges and other kitchen machinery, et cetera, can be used for greening various private and public buildings. Construction of green roofs in urban areas results in double benefit and a win-win situation between the building’ owner and the local society. Therefore, due to external benefits of the green roofs their construction in urban communities should be subsidized with public funds. Further research should be focused on studying hybrid energy systems combining the construction of green roofs and the installation of semi-transparent solar-PVs on rooftop of buildings.

### 7. CONCLUSIONS

The contribution of green roofs in the achievement of the UN SDGs has been analyzed. Our findings indicate that green roofs have many environmental, economic and social impacts

which are related with the achievement of several SDGs including: a) SDG3, good health and well-being, b) SDG11, sustainable cities and communities, c) SDG13, climate action, d) SDG15, life on land. Construction of green roofs on rooftops of buildings in urban communities has multiple benefits such as: a) mitigation of UHI effect, b) absorption of atmospheric pollutants including CO<sub>2</sub> via plants’ photosynthesis, c) possibility for developing small scale urban agriculture, d) reduction of the energy demand in the building and decrease of energy-related carbon emissions, e) creation of an urban habitat attracting fauna, f) increase of the life span of the building and its commercial value, g) improvement of the rainwater management, h) improvement in the health and the wellbeing of the nearby residents, and i) mitigation of climate change. Taking into account that green roofs have many external benefits which are not related with the benefits of the residents of the buildings their construction should be partly subsidized with public funds. This is common practice in many EU countries. Our results could be used by policy makers and municipal authorities who should develop robust policy measures for the promotion of green roofs in urban areas.

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