Green roofs in Oslo by 2030:

Co-creating a common understanding of impacts and relevance for the city

A participatory workshop hosted by URBAG:

Integrated System Analysis of Urban Vegetation and Agriculture

29th of January 2024

Results

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Executive Summary

- Green roofs provide ecosystem services in urban areas, helping mitigate vulnerabilities. However, the spatially explicit impacts of different green roof configurations in urban environments, especially regarding off-site (non-urban) impacts, remain understudied.
- Oslo's municipality is committed to enhancing urban conditions by employing green roofs, guided by the Strategy for Green Roofs and Facades, which offers guidelines for the creation of new green roofs.
- To evaluate the effectiveness of green roofs, URBAG is examining potential implementation scenarios in Oslo by 2030, considering its impacts on both local (within city limits) and broad-scale vulnerabilities (outside city limits).
- Given the complex nature of assessing the multifaceted impacts of green roofs, a stakeholder process involving scientists, urban planners, policymakers, and NGOs took place in order to:
  - Determine the impact relevance of green roofs on local and global vulnerabilities.
  - Assess how policy-making strategies might benefit from the green roof assessment results.
- Findings show green roofs reduce local vulnerabilities but increase broad-scale vulnerabilities in all scenarios.
- Stakeholders prioritize local vulnerability impacts over broad-scale ones.
- Based on stakeholder feedback, a most favorable scenario was developed, proposing 706 hectares of green roofs (68% of potential) to maximize local benefits and minimize broader undesired impacts.
- The vulnerability assessment approach is valued by stakeholders for its capacity to raise awareness around the importance of nature in cities, justifying financial support, improving spatial planning, and providing insights for expanding the Blue-Green Factor considerations.

1. Introduction

Rooftops are often unused areas and offer an opportunity for the implementation of green spaces, which can help reduce risks posed by climate change and increased densification. The Municipality of Oslo is currently pushing for active planning and development of green roofs to achieve the city´s 2030 urban targets, through initiatives such as the Green Roof Strategy and the Blu-green factor score in urban property development.

In this context, it's crucial to comprehend the possible implementation scenarios of green roofs and to estimate both their desired and undesired effects. These effects include the environmental consequences of constructing and maintaining green roofs, as well as the ecosystem services that they provide. This understanding is essential for assessing how effectively green roofs can enhance urban conditions. URBAG has taken on this challenge by conducting a comprehensive evaluation of green roof possibilities for Oslo's municipality by the year 2030. This assessment covers a range of implementation scenarios and focuses on vulnerability shifts in the city. The vulnerability approach provides a common ground for interpreting different impacts arising from green roofs in both spatially explicit and non-spatially explicit ways.

A comprehensive analysis is needed to determine the impacts of green roofs on the city, considering changes in vulnerability, tradeoffs, and synergies aligned with Oslo's urban goals. Due to the complex nature of assessing multifaceted consequences, a stakeholder process involving scientists, urban planners, policymakers, and NGO representatives is underway. This collaborative approach, focusing on urban sustainability and nature-based solutions, enables a holistic evaluation of the intricate interactions and impacts of green roof implementation.

Figure 1. The assessment focuses on the impacts of extensive green roofs (Photo: Økern Portal)

2. Workshop objectives

- To determine the relevance of the impacts resulting from the implementation of green roofs in the Municipality of Oslo on local and global vulnerabilities.
- To assess whether policy-making strategies could benefit from the results obtained in the green roof assessment.

3. Workshop Agenda

Green roofs in Oslo by 2030

Co-creating a common understanding of impacts and relevance for the city

Agenda

13:00	**Welcome and Introduction**
13:10	Research project background, objectives and relevance of the Oslo case study (Gara Villalba / ICTA-UAB)
13:15	Crafting Policies for Green Roofs: Oslo's green roofs strategy and Blue-green factor (Tore Mauseth / Oslo Kommune)
13:30	Integrated assessment of green roofs in the Oslo Municipality: impacts on cross-scale vulnerabilities (David Camacho / ICTA-UAB)
13:50	Q&A
14:10	Workshop 1: Discussion and weighting of the impacts of green roofs within and beyond Oslo's boundaries
15:10	Break
15:20	Workshop 2: Development of strategies for integrating the cross-scale impacts of green roofs into policy and planning
16:00	**Closure**

Figure 2. Agenda for the workshop *Green roofs in Oslo by 2030: Co-creating a common understanding of impacts and relevance for the city*

4. Methods

The assessment is based on the premise that cities are dynamic and interconnected systems, involving both the natural environment and social aspects that interact on various levels. Within these urban systems, the implementation of nature-based solutions (e.g., green roofs) provide both desired and undesired effects. Our approach intends to comprehensively evaluate these effects, by understanding how they influence local-scale vulnerabilities (within city limits) and broad-scale vulnerabilities (outside city limits). Broad-scale vulnerabilities are defined by the Planetary Boundaries, which are defined as the "safe operating limits within which humanity can operate to maintain a stable and resilient global environment" (Rockström et al., 2009).

__Vulnerability__ is the susceptibility to harm of both social and ecological systems.

The creation of green roofs can shift both local-scale vulnerabilities (found within urban limits) and broad-scale vulnerabilities (found beyond urban limits)

Local-scale vulnerabilities are assessed employing two types of indicators: exposure indicators, which relate to the presence of hazards (e.g., temperatures during heatwaves, lack of green spaces, floodable areas), and sensitivity indicators, which depict the extent to which a system is impacted by hazards (e.g., presence of elderly and children, and low-income households). Broad-scale vulnerabilities are assessed using only exposure indicators and. These do not consider the sensitivity dimension of vulnerability since it is assumed that global impacts such as global warming and ozone depletion affect global populations and ecosystems as a whole.

For the simultaneous consideration of different impacts arising from the green roof implementation, a multi-criteria decision analysis (MCDA) approach is taken. MCDA proves to be a valuable instrument in creating comprehensive evaluations of urban Nature-Based Solutions (NBS) facilitating the incorporation of several indicators for the calculation of each of the vulnerabilities, and the perspectives of stakeholders into decision-making processes.

The assessments have been designed for the study of extensive green roofs only. For the calculation of the impacts on vulnerabilities, several methodologies have been employed, including Life-cycle assessment, Geographic Information Systems (GIS), Weather Research and Forecasting model simulation, among others.

5. Scenarios of green roof implementation

Four scenarios are proposed to understand the possible growth trends of green roofs in the city of Oslo, which were revised with stakeholders with experience in managing this and other types of NBS (URBAG, 2021). Scenarios portray the single land-use change from rooftops without green roofs to rooftops with green roofs. **Figure 3** offers a scenario overview.

The scenarios are:

- Current (S0) which serves as the reference state and is based on an aerial photo-survey conducted by the Oslo municipality in 2017 (Oslo Kommune, 2021b), identifying 928 green roofs covering 18 hectares.
- Green roof strategy (S1), which aligns with the objectives outlined in the municipal strategy for the increase of green roofs and facades by 2030 (Oslo Kommune, 2022), projecting 2030 green roofs and covering 41 hectares.
- Ambitious (S2), representing an optimistic implementation of green roofs in the municipality, larger in scale than scenario S1, with 3,550 green roofs covering 72 hectares.
- Maximization (S3), representing the creation of green roofs in all available rooftops of the city with an area bigger than 10m2 and a slope below 30°, resulting in 56,786 green roofs covering 1,039 hectares.

Location and size of new green roofs for S1, S2 were chosen based on the premise of maintaining the spatial distribution and average size of green roofs found in S0.

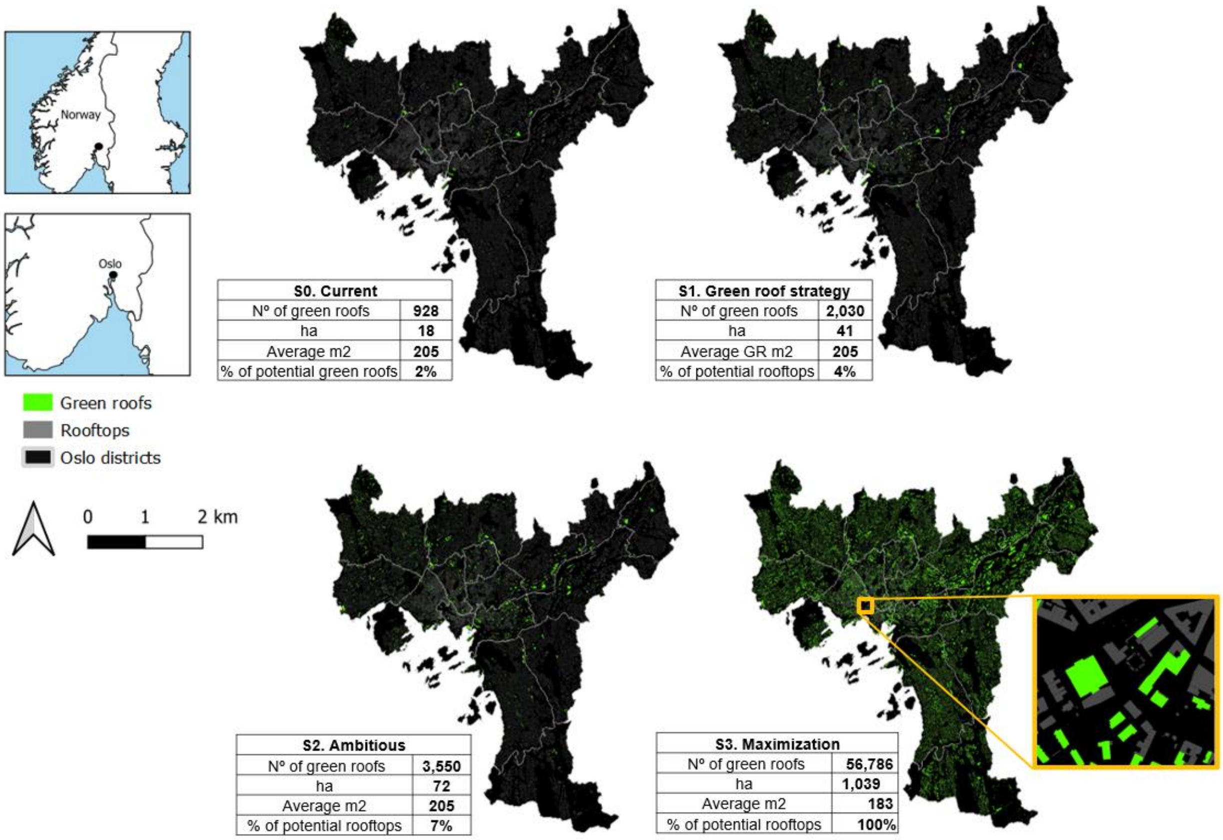

Figure 3. Proposed scenarios for estimating green roofs impacts on local and broad-scale vulnerabilities, depicting the number of green roofs, their total extension, average size and percentage occupation out of the total potential green roofs

6. Description of vulnerabilities

To assess the impacts of green roofs, both local-scale vulnerabilities (experienced within urban limits) and broad-scale vulnerabilities (experienced beyond urban limits) were selected. These were chosen based on Oslo's urban objectives and Norwegian or European guidelines.

6.1. Local-scale vulnerabilities

6.1.1. Vulnerability of lack of habitats for pollinators

Oslo's location, with a short distance between the fjord and Marka and special ecological conditions, makes it the municipality in Norway with the highest record of biodiversity (Oslo Kommune, 2023b). Oslo is actively working on preserving biodiversity conditions, considering that many biologically valuable habitats will be exposed to strong urban development pressure due to population growth in the city (Oslo Kommune, 2023a). In this sense, green roofs can improve urban conditions by increasing the presence and foraging of pollinators (Kratschmer et al., 2018; Passaseo et al., 2020).

To evaluate this vulnerability, we include the Pollinator habitat suitability as the exposure indicator, and Precautionary zones for honeybee keeping and Areas with presence of red listed bee species as sensitivity indicators.

6.1.2. Vulnerability to heavy rainfall events

Green roofs have been described as a valuable option for stormwater management within urban environments as they are able to retain rainwater for enough time to delay peak water discharges (Shafique et al., 2018). Norway anticipates an increase in periods of heavy local precipitation, which will add pressure to the stormwater management systems across their cities (Norwegian Directorate for Civil Protection, 2019). Oslo municipality is preparing for such climatic conditions, that, coupled with a growing population and the development of more densely populated urban areas, are expected to heighten its vulnerability to heavy rainfall events (Oslo Kommune, 2023b). In this sense, green roofs offer solutions for reducing urban runoff due to their capacity to retain during rain periods (Oslo Kommune, 2012).

To assess the exposure to heavy rainfall events, the indicator selected was the runoff coefficients observed for an average annual rainfall of 800 mm and a storm event with a one in 10-year recurrence. The sensitivity indicators selected were areas with the presence of critical infrastructure, population density, elderly population density and low-income households.

6.1.3. Vulnerability to heat

Summer temperatures in Oslo are expected to rise 5.6 °C in a scenario of moderate climate change, assuming alignment with the goals of the Paris Agreement (Bastin et al., 2019). The municipality of Oslo is aware of its exposure to heat risks and intends to become a climate-resilient city (Oslo Kommune, 2020). Similar to other urban green infrastructures, green roofs offer temperature regulation during heatwaves, both within and outside of buildings (Jaffal et al., 2012; Liu et al., 2021).

For assessing Vulnerability to heat, three exposure indicators were selected: outdoor heatwave day and night temperatures, and indoor heatwave day temperatures. Sensitivity indicators include population density, elderly population density and low-income households.

6.1.4. Vulnerability to air pollution

Air pollution in Oslo has steadily decreased over the last decades due to local measures, but more efforts are required since exceedances from pollutants associated with road traffic and domestic heating still occur (Oslo Kommune, 2021b). The use of vegetation as a passive filter of urban air has been previously investigated, including extensive green roofs (Gourdji, 2018; Speak et al., 2012), showcasing positive outcomes.

For this vulnerability, the selected exposure indicators were the presence of particulate matter smaller than 10 μm (PM10), along with population density, children population density, and low-income households as sensitivity indicators.

6.2. Broad-scale vulnerabilities

6.2.1. Vulnerability to climate change

Vulnerability to climate change is defined by the Planetary Boundary "Climate Change", described as a notable deviation from the established patterns of natural variability witnessed throughout the Holocene era. Their impacts may encompass swift sea level escalation (approximately 1 meter or more per century), disturbances in regional climates caused by droughts, floods, and other extreme phenomena, as well as high rates of biodiversity depletion, which directly impact the ecosystem services they sustain Rockström, et al., 2009). Climate change Planetary Boundary is measured by atmospheric CO2 concentration.

Oslo municipality has pushed for a reduction of CO2 emissions for the city development, aiming Oslo's greenhouse gas emissions in 2030 to reduce them by 95 % compared with 2009 (Oslo Kommune, 2021a).

The creation and maintenance of green roofs can be associated with CO2 emissions due to the manufacturing of fertilizers, as well as the construction and transportation of layers (Bozorg Chenani et al., 2015). Nonetheless, green roofs also offer CO2 sequestration benefits throughout their lifetime (Whittinghill et al., 2014).

6.2.2. Vulnerability to stratospheric ozone depletion

Vulnerability to stratospheric ozone depletion is defined by the Planetary Boundary "Stratospheric Ozone Depletion", which focuses on the maintenance of the ozone layer in the Earth's stratosphere. The ozone layer, located in the stratosphere, filters (UV) radiation from the sun. In the past, the combination of heightened levels of anthropogenic ozone-depleting substances, such as chlorofluorocarbons, along with the presence of polar stratospheric clouds has led to the ozone effectively disappearing in the lower stratosphere (Rockström, et al., 2009). The depletion of the stratospheric ozone layer has adverse effects on marine organisms and presents health hazards to human populations (Rockström, 2009).

Norway's national targets on climate change, air pollution, and noise aim to eliminate the consumption of halons, all types of chlorofluorocarbons (CFCs), tetrachloromethane, methyl chloroform, and hydrobromofluorocarbons (HBFCs) (Miljøstatus, 2023).

The creation of green roof substrates has been linked to the emissions of chlorofluorocarbon gases, which affect the ozone layer (Bozorg Chenani et al., 2015).

6.2.3. Vulnerability to novel entities

Vulnerability to novel entities is defined by the Planetary Boundary "Novel Entities", described as new anthropogenic introductions to the Earth system. These encompass a range of synthetic chemicals and substances such as microplastics, endocrine disruptors, and organic pollutants. Additionally, they include anthropogenically mobilized radioactive materials, including nuclear waste, as well as human modifications of evolution through genetically modified organisms and other direct interventions in evolutionary processes (Richardson et al., 2023).

Since 1981, Norway's Pollution Control Act which intends to protect the outdoor environment against pollution and to reduce existing pollution, to reduce the quantity of waste and to promote better waste management (Ministry of Climate and Environment, 2023). For this matter, green roof's fabrication of layers and fertilizers often involves pollution emissions related to both water and terrestrial toxicities (Shafique et al., 2019).

6.2.4. Vulnerability to changes in biochemical flows

Vulnerability to changes in biogeochemical flows is defined by the Planetary Boundary "Biogeochemical flows: P and N cycles", which reflects on anthropogenic perturbation of global element cycles (Richardson et al., 2023). As of now, the PB framework acknowledges nitrogen (N) and phosphorus (P) due to their crucial roles as fundamental building blocks of life, with their global cycles significantly altered by agricultural and industrial activities. Human activities, primarily through the manufacture of fertilizer for food production and the cultivation of leguminous crops, convert approximately 120 million tonnes of N_2 from the atmosphere into reactive forms each year (Rockström, 2009). Altered nutrient flows and element ratios have profound effects on ecosystem composition and long-term Earth system dynamics.

To address this issue, phosphorus and nitrogen emissions from Norwegian commercial activities are intended to be reduced (Maass et al., 2021) to limit acidification and eutrophication effects on natural environments. These impacts have been observed in green roof creation and management due to fertilization practices (Shafique et al., 2019).

7. Results

7.1. Speakers

The participatory workshop featured several presentations designed to provide participants with foundational knowledge for the workshop's interactive activities. The presentations included:

- Gara Villalba "Urban Green Infrastructures are Key Stones in Building Resilient Cities": this presentation covered the research premises from URBAG, results from previous case studies using the Nature-Based Solutions vulnerability approach, and the significance of the green roof case study in Oslo for the understanding of NBS' impacts.
- Tore Mauseth "Crafting Policies for Green Roofs": focused on Oslo's municipal efforts to develop green roofs and green walls by 2030, highlighting the implementation of the blue-green factor as a guiding principle for new developments.
- David Camacho-Caballero "Integrated Assessment of Green Roofs: Vulnerability Assessment": introduced participants to the methodological premises of the Nature-Based Solutions vulnerability framework. He shared results from applying this framework to assess the impacts of green roofs, highlighting expected impacts on both local and broad-scale vulnerabilities.

For accessing each of the presentations, please visit the following link Integrated assessment of green roofs: presentations.

7.2. Exercise 1: weighting of vulnerabilities

After viewing the presentations, stakeholders were divided into two different groups and asked to evaluate and rank the vulnerabilities they considered more or less relevant to take into account for green roof implementation in Oslo, based on their professional criteria. Stakeholders ranked both local and broad-scale vulnerabilities from most to least relevant, in the following order: *Vulnerability* *to heavy rainfall events, Vulnerability to lack of habitats for pollinators, Vulnerability to lack of opportunities for interacting with natural environments, Vulnerability to heat, Vulnerability to climate change, Vulnerability to air pollution, Vulnerability to novel entities, Vulnerability to changes in biogeochemical flows* and *Vulnerability to stratospheric ozone depletion* (see **Figure 4** for weight distribution).

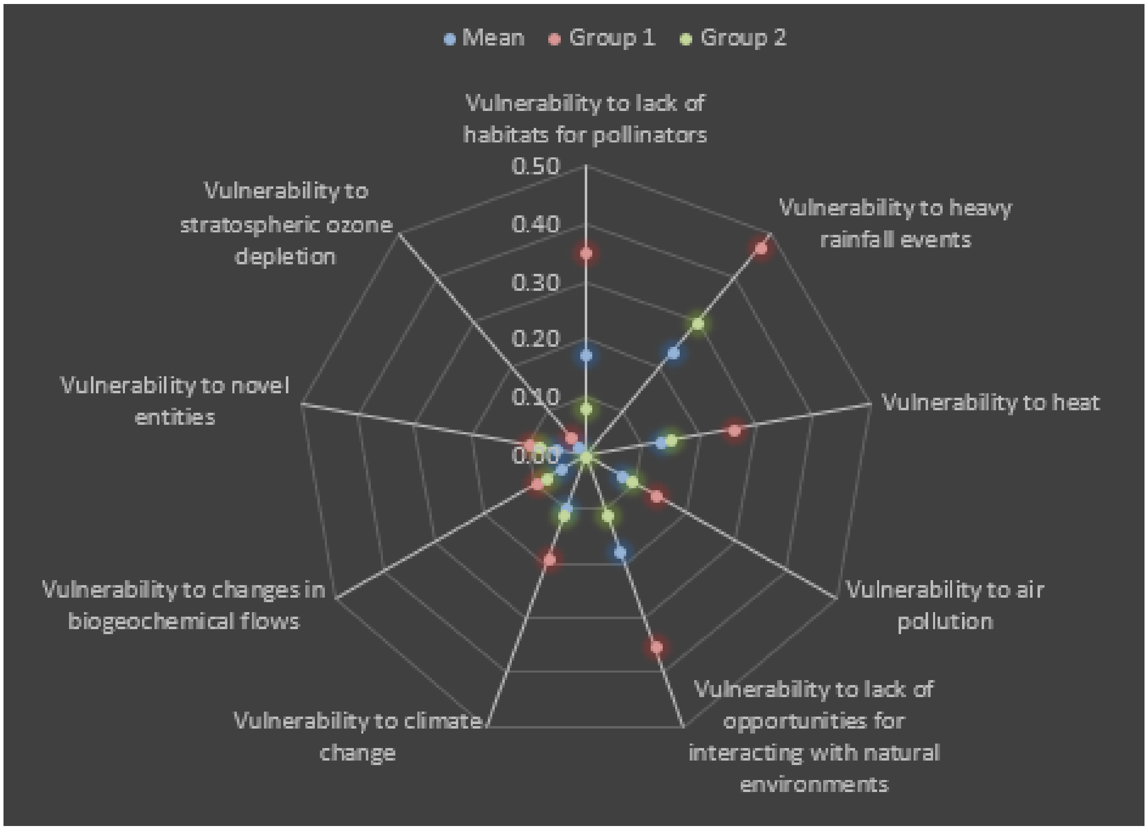

Figure 4. Group weighting of vulnerabilities relevant to consider when implementing green roofs in the city of Oslo

7.3. Exercise 2: policy relevance

Stakeholders were asked to brainstorm ideas in response to the following question: *Could any policy measures or strategies be implemented based on the green roofs' impacts presented today?* Their responses addressed both the significance for green roofs planning and green infrastructure in general. The responses were grouped into four categories:

- ***Awareness raising***

Stakeholders emphasized that a vulnerability approach could be effective for raising awareness about the importance of green areas in the city. This approach highlights not only their relevance for stormwater management but also broader benefits such as local nature and public health. Raising awareness was identified as a catalyst for financial support and behavioral change, underscoring the need for continuous research and education.

Additionally, stakeholders noted that the evaluation framework could be used to identify areas for public education on stormwater management and flood security, teaching residents how to protect their homes against flooding.

- ***Spatial planning***

Stakeholders suggested that the vulnerability approach could assess nature loss and gain in Oslo, helping justify policies to reverse this trend even as the city densifies. They emphasized the importance of integrating green infrastructure to meet international and European environmental obligations.

Furthermore, a long-term green roof policy would benefit from the current assessment by managing local resources and establishing spatial priority areas for green roof implementation.

- ***Financial support***

Stakeholders highlighted that results from the vulnerability assessment could help justify the need for further financial assistance to support green roof implementation. Recommendations included setting minimum standards for green infrastructure in municipal projects, along with financial and social incentives for adopting green roofs. Specific suggestions included municipal financial support for private entities and incentive programs for landowners and developers to enhance biodiversity in areas with the greatest need. Financial assistance should target private buildings in flood-prone areas to encourage widespread adoption.

- ***Blue-green factor***

The Blue-Green Factor approach could incorporate results from vulnerability assessments to complement its scoring system, considering NBS impacts on both local and broad-scale vulnerabilities. Additionally, stakeholders proposed integrating life cycle assessment impacts into the Blue-Green Factor "menu" to ensure comprehensive environmental accounting.

These suggestions aim to refine the BGF approach, ensuring that green roofs contribute effectively to reducing vulnerabilities and enhancing ecosystem services.

7.4. Co-creation of a most favorable scenario

Stakeholder weights and equal weights were employed for producing a new scenario: the most favorable scenario (S4) portraying the optimal area of green roof to maximize desired impacts on vulnerabilities (reduction of local-scale vulnerabilities) while minimizing undesired impacts (increases in broad-scale vulnerabilities).

When using stakeholder weights, the optimal area was found to be 706 hectares of green roofs, accounting for 68% of the potential green roofs that could be implemented in Oslo. Conversely, equal weights reduced the area of green roofs to 160 hectares, constituting only 15% of the potential green roofs.

Calculations for S4 under both weighting schemes are spatially portrayed in **Figure 5**, where Oslo areas are prioritized for the implementation of green roofs to simultaneously maximize desired impacts and minimize undesired impacts on vulnerabilities.

Stakeholder weights allow for greater implementation of green roofs in Oslo (see **Fig. 5a**), as these give preference to the desired impacts on local-scale vulnerabilities before the undesired impacts on broad-scale vulnerabilities. High-priority areas are found in the city center, mainly in the coastal area, while low-priority areas expand across the rest of the urban space. A similar concentration is found under equal weights (see **Fig. 5b**), but much less widespread, as equal weights do not allow for such a great implementation of green roofs, as these expansions increase undesired impacts on broad-scale vulnerabilities.

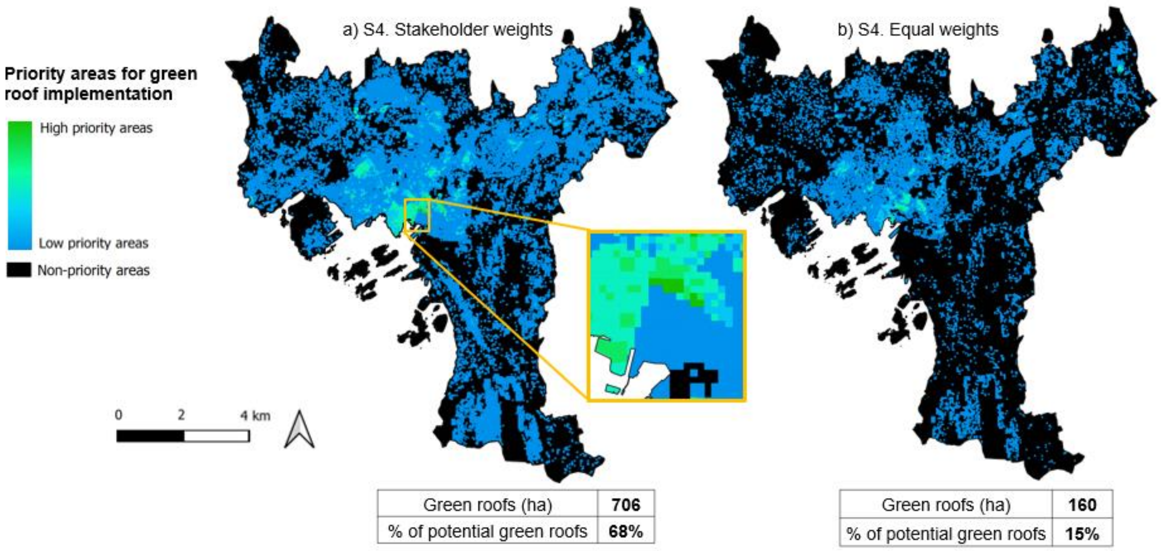

Figure 5. Priority areas for green roof implementation based on a most favorable scenario where desired impacts are maximized and undesired minimized. Two weighting schemes are considered, along with their respective green roof extensions and percentage occupation out of the total potential green roofs.

8. Conclusions

The objective of this workshop was to collaboratively assess the potential impacts of various green roof implementation scenarios in Oslo by 2030. A novel methodology developed by URBAG was employed, evaluating how green roofs could affect both local (within city limits) and broad-scale vulnerabilities (outside city limits).

Our initial assessment provided stakeholders with information on how green roofs can mitigate local vulnerabilities, such as heatwaves and stormwater management. However, it also highlighted that green roofs might exacerbate broader environmental vulnerabilities due to the lifecycle impacts of their construction and maintenance. These findings gave stakeholders a common understanding of possible synergies and trade-offs. Based on this information, stakeholders prioritized the vulnerabilities they deemed most relevant for green roof implementation in Oslo, favoring local vulnerability impacts over broad-scale ones.

These priorities were used to create the most favorable scenario, involving 706 hectares of green roofs (68% of potential), aiming to maximize local benefits while minimizing broader undesired impacts. This scenario considers the cross-scale impacts of nature-based solutions employing stakeholders' preferences, depicting conditions where synergies are maximized, and trade-offs are reduced. It provides a clear and understandable overview of where and how green roofs could be most effective.

In summary, the participatory stakeholder workshop facilitated a novel understanding of green roof impacts (and NBS in general), considering both desired and undesired impacts across spatial scales. This novel approach and its results could further benefit urban planning and policy development around NBS by raising awareness about the importance of nature in cities, justifying financial support, improving spatial planning, and providing insights for expanding the Blue-Green Factor considerations.

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