energies

MDPI

Article

The Use of Nature-Based Solutions in the Adaptation of Large Polish Cities to Climate Change and Energy Transformation: A Comparative Analysis

Alina Pancewicz *, Dominika Bednarz, Dawid Drożdż, Monika Marszoł and Natalia Suchy

Faculty of Architecture, Silesian University of Technology, 44-100 Gliwice, Poland
* Correspondence: alina.pancewicz@polsl.pl; Tel.: +48-32-237-13-18

Abstract: Cities have always been places that generate problems, but also places where solutions are born. In recent years, cities have become a testing ground for finding and testing solutions to overcome the climate crisis. The subject of the paper is Nature-based Solutions (NbSs) that strengthen the resilience to climate change, influence urban spaces, and improve the quality of life of residents. The study focusses on the identification of NbSs, the diagnosis of its participation in local adaptation activities, and a comparative analysis of the activities planned and implemented in 44 large Polish cities in 2017–2023. The authors analyse data from 44 Polish cities, based on the types of NbSs implemented in European cities that carried out the URBAN GreenUP project. The results of the study show that Polish cities, while introducing sustainable urban lifestyles through NbSs, do not take advantage of all the opportunities inherent in these solutions. They focus on greening urban spaces and implement water interventions and singular green infrastructure measures to a lesser extent. There is negligible use of innovative and energy-using activities. The quantitative data obtained can be used to identify the gaps and potentials in the use of nature-based solutions in the adaptation of Polish cities to climate change and energy transformation. The aim of this work is also to identify recommendations to incorporate NbSs into urban adaptation policies in Poland. The authors conclude that the research conducted can serve to improve the knowledge on the links between NbS planning in adaptation activities and their implementation in urban spaces. An awareness of NbS gaps can influence the intensification of research on the implementation of innovative adaptation solutions, including energy-based solutions. The results obtained can also contribute to a better organisation of urban policies that aim to increase the resilience of cities to climate change.

Keywords: urban climate policy; adaptation activities; sustainable urban spaces; energy transition

Citation: Pancewicz, A.; Bednarz, D.; Drożdż, D.; Marszoł, M.; Suchy, N. The Use of Nature-Based Solutions in the Adaptation of Large Polish Cities to Climate Change and Energy Transformation: A Comparative Analysis. *Energies* **2023**, *16*, 5189. https://doi.org/10.3390/en16135189

Academic Editors: Kinga Stecuła, Katarzyna Markowska and Artur Dyczko

Received: 22 April 2023
Revised: 29 May 2023
Accepted: 8 June 2023
Published: 5 July 2023

1. Introduction

1.1. Context of the Issue and Purpose of the Research

The search for sustainable urban lifestyles is part of the history of human settlement [1,2]. With economic, political, social, or cultural changes, not only have urban spaces changed, but so have the quality and lifestyle of residents. One of the key urban challenges of recent years has been progressive climate change. These have demonstrated the inadaptability of urban spaces and their high vulnerability to the hazards of extreme temperatures, intense precipitation, seasonal storms, or strong winds. The planning and implementation of adaptation activities for identified hazards are currently an integral part of urban development policy [3]. It is also the subject of testing and prototyping solutions for so-called urban and social resilience. The need to adapt cities to climate change is also seen as an opportunity for transformation towards the low-carbon, innovation, and environmentally and human-friendly management of urban areas. One option to adapt urban spaces to climate change and, at the same time, introduce sustainable urban lifestyles is nature-based solutions (NbSs). These include many complementary and interrelated

aspects of urban life, infrastructure, and ecosystem services [4]. Their basis is the use of the characteristics of the elements of the natural environment to shape urban spaces and solve socioeconomic and environmental problems [5]. NbSs remove CO_2 and can also prevent the release of greenhouse gases. NbSs could provide around 30% of the cost-effective mitigation to stabilise warming to below 2 °C by 2030 [6]. The use of NbSs can also result in significant energy savings. Some of the NbSs are based on the use of renewable energy sources or energy-saving technologies.

The subject of the paper is actions based on natural capital that strengthen the resilience of cities to climate change, influence the formation and transformation of urban spaces, and the lifestyle of residents. The study focusses on the identification of NbSs, the diagnosis of its participation in adaptation activities, and the comparative analysis of the activities planned and implemented in Polish cities between 2017 and 2023. The authors analyse data from 44 large Polish cities, based on the types of NbSs considered in European cities implementing the URBAN GreenUP project under the European Union's Horizon 2020 [7]. The aim of the research is to identify gaps and potentials in the use of NbSs in the process of the adaptation of Polish cities to climate change and energy transformation. An important aim is also to identify recommendations for the integration of NbSs into urban adaptation policies. The results of the study allowed the authors to determine the number of planned and implemented NbSs, analyse their distribution relative to urban areas, and see which activities are most and least planned and implemented. The results of the research have highlighted the extent to which large Polish cities, in preparation for and adapting to climate change, rely on the potential of natural solutions and the extent to which they take into account the possibility of using energy in the process.

1.2. State of Research

The term 'Nature-based Solutions' first appeared in 2008 in the publication 'Biodiversity, Climate Change, and Adaptation: Nature-based Solutions from the World Bank Portfolio' [8]. Over the years, numerous publications or reports on NbSs have been published. They concerned, among other things, how NbSs are implemented and how they operate [9–12], the impact of NbSs on cities [13,14], and their development policies [15]. An important issue described in the reports is the relationship between NbSs and the reduction in disaster risk [16]. In many studies, research papers, or articles, NbSs are described in the context of sustainable green infrastructure [17–21] or water management [22–26]. The important aspect of NbSs is also its impact on human health and well-being [27]. The contribution of NbSs to urban transformation is presented more and more often in relation to the process of strengthening the resilience of urban spaces [28]. There is also a noticeable connection between NbSs, strengthening urban resilience, the challenge of sustainable development [29,30], and the use of new technologies in the context of the circular economy [31]. In recent years, some publications have also pointed to the links of NbSs with energy production and energy transition [32–36]. Such correlations, combined with other advantages of NbSs, generate multiple benefits for both the natural environment and the urban environment and the people who function in them [37].

1.3. URBAN GreenUP: Innovative NbS in European Cities

URBAN GreenUP is a project that has been implemented from 2017 to 2022. The aim of the project was to implement innovative NbSs to mitigate the effects of climate change, protect the natural environment, improve the quality of life of the residents, and increase urban sustainability. The project, coordinated by the CARTIF Technology Centre, was based on the 'Renaturing Urban Plans' in European and non-European partner cities.

The effectiveness of the implemented methodology was tested in three pilot cities: Valladolid (Spain), Liverpool (UK), and Izmir (Turkey). The conclusions were applied in five more cities: Mantova (Italy), Ludwigsburg (Germany), Medellin (Colombia), Chengdu (China), and Binh Dinh-Quy Nhon (Vietnam). As stated in the presumptions, the achievement of diverse effects related to environmental and socioeconomic aspects in cities has

been made possible through activities implemented through re-naturing urbanisation, water interventions, singular green infrastructures, and non-technical interventions. These activities implement sustainable urban policies aimed at mitigating the effects of climate change. Part of this is to invest in cutting-edge research and innovation, and environmental protection, in ways that bring tangible benefits to residents. Among the proposed solutions covering various aspects of urban life are those that reduce greenhouse gas emissions; improve air quality; increase waterfront resilience; restore degraded areas; allow for the better management of green spaces, water, health, and social well-being; and enable participatory planning and management. Among the NbSs, there are some that reduce the energy consumption from fossil fuels and expand the use of energy from renewable sources. Various types of biofilters, smart soils, properly selected plant species, and purposefully greened urban areas foster climate neutrality; decarbonisation; CO_2 reduction; the improvement of air quality; a reduced heat island effect; sustainable production and consumption; and a balance of flow, temperature, humidity, and contaminants concentration, and adds aesthetic values to urban areas, etc. [7].

An example of an NbS, studied within the URBAN GreenUP project, is 'Smart soil production in climate-smart urban farming precinct'. This solution has a significant contribution to climate mitigation. It involves the use of pyrolysis technology and the conversion of biomass into biocarbon, which can be a potential carbon-negative energy source. Smart soil production will allow its usage in degraded areas, urban wastelands, soil-poor areas, and areas adjacent to developed residential areas or transportation areas [38].

Another NbS that involves energy is an 'Electro wetland'. It involves a natural wastewater treatment method that generates electricity from the oxidation of organic matter. The project is based on the flow of wastewater through a gravel-filled tank, cut by a subsurface layer (HSSF CW), into which electrodes are inserted. Energy is generated from interconnected electrodes that stimulate the development of an exoelectrogenic biofilm, which carries electrons generated by the degradation of organic matter to the outer circuit [39].

Innovative NbSs researched, planned, and implemented in partner cities as a result of the URBAN GreenUP project foster climate change mitigation and promote the transformation of cities towards sustainability. These projects can also stimulate activities in various cities not related to the project that are undergoing energy transition and pursuing climate resilience.

1.4. Strategic Planning of Poland's Urban Adaptation Policy

Climate change and its ongoing proceedings require ensuring the safety of urban residents and the continuity of sustainable development. In this situation, it is important to shape local policies aimed at planning and implementing solutions to increase the resilience of cities to climate change. In Poland, Urban Adaptation Plans (UAPs) are the basic urban policy documents crucial for shaping adaptation policies and effectively raising funds for urban adaptation activities. These documents were created in 2017–2019, as part of a project by the Ministry of Environment to assess the vulnerability to climate change in Poland's 44 large cities (more than around 100,000 inhabitants) [40]. Work is currently underway in Poland to prepare UAPs for cities with a population of more than 20,000. The provisions contained in these documents are an important complement to other local strategic, planning, and programming studies, such as studies of the conditions and directions of urban development, urban development strategies, low-carbon management plans, environmental protection programmes, and revitalisation programmes. Actions aimed at reducing and slowing climate change undertaken by local governments in Poland can be divided into long-term and ad hoc interventions. Long-term actions focus on city policies, social programmes to raise public awareness of ongoing changes, and investments that affect the functionality and spatial structure of the city. Ad hoc interventions provide temporary protection against the effects of climate dangers in urban spaces. The achievement of sustainable development and the effective functioning of the economy and society

under climate change conditions are possible through the implementation of both types of activities [41].

2. Materials and Methods

The paper is the result of research based on our need to find out whether and to what extent Polish cities take into account the need to plan and implement NbSs. An important research question is how many of these solutions innovate and use energy. We conducted in-depth research on 44 large Polish cities that participated in the project of the Ministry of Environment 'Development of Urban Adaptation Plans for Cities with more than 100,000 inhabitants in Poland', implemented in 2017–2019. All cities surveyed have adopted Urban Adaptation Plans (UAPs), in which they have planned activities to strengthen the resilience of urban spaces and allow them to protect themselves from the effects of climate change. The essence of the research is to investigate whether Polish cities with development policies aimed at increasing the resilience of urban spaces implement NbSs. Part of the research is a comparative analysis of the results obtained for all Polish cities surveyed and situating them in the context of the European project URBAN GreenUP.

We based our research method on the collection and analysis of baseline data to identify NbSs in Polish cities. The baseline data for the research were collected by first-year master's students of the Faculty of Architecture at the Silesian University of Technology. The research covered the years from 2017 to the end of January 2023 [42]. Among the sources of data, there were local strategic, planning, and programme documents, i.e., city development strategies, studies of land use conditions and directions, and municipal revitalisation programmes. The data extracted also came from the national Operational Programme Infrastructure and Environment, data from civic budgets, websites of municipal offices, environmental institutes and foundations, urban green boards, information portals, and others. Of the collection of documents analysed, some of the most important data sources were UAPs. The review, reading, and analysis of the sources became the basis for identifying and classifying NbSs.

We grouped the spatial studied solutions into three categories: re-naturing urbanisation, water interventions, and singular green infrastructure activities. These cover a variety of complementary and interrelated aspects of urban spaces and infrastructure. The typology of NbSs coincides closely with the assumptions of the URBAN GreenUP project and involves limiting the identified NbSs in Polish cities to the categories and types of the project. We assigned individual NbSs implemented in Polish cities (not included in the typology of URBAN GreenUP) in each category to the 'other' groups. The standardisation of the typology makes it possible to compare, analyse, and evaluate the results of the planned and implemented Polish initiatives with the activities undertaken in the pilot cities of the URBAN GreenUP project. The authors are aware that standardising the criteria for the selection of solutions makes it less possible to take into account the individual circumstances and specificities of the cities under study. On the other hand, however, this approach emphasises the universal character of NbSs and highlights differences in the scope of individual measures, including those that innovate or use energy. We did not include non-technical interventions in the research, including information, education, and organisational activities, which, although they play an important role in UAPs, are often not directly reflected in urban spaces.

The categories analysed in the paper and the types of NbSs that are most representative of them include:

a. Re-naturing urbanisation:
    - Arboreal interventions: planting and renewing urban trees, cooling trees, shade trees, arboreal areas around urban areas, trees re-naturing parking, urban carbon sink;
    - Pocket parks and parklets;
    - Green resting areas;
    - Cycle and pedestrian green routes.

b. Water interventions:
   - Flood control infrastructure investments: rivers and channels re-naturalisation; flood actions: floodable parks, hard drainage-flood prevention, urban catchment forestry;
   - Green pavements: cool pavement, cycle-pedestrian green paths, green parking pavements, hard drainage pavements;
   - Pollution-filtering areas: natural wastewater treatment, green filter area;
   - Drainage systems: rain gardens, grassed swales and water retention pounds, sustainable drainage systems (SUDSs).

c. Singular green infrastructure:
   - Vertical activities: green walls, hydroponic green facades, green facades with climbing plants, vertical gardens, green noise barriers, green fences;
   - Horizontal activities: green roofs, green shady structures, green covering shelters, electro wetlands, floating gardens;
   - Urban farming: small-scale urban livestock, community composting, urban orchards, climate-smart greenhouses;
   - Pollutants filters: urban garden bio-filters; green filter areas;
   - Pollinators: compacted pollinator modules, natural pollinator modules, pollinator roofs, pollinator walls, pollinator verges and spaces;
   - Smart soils: smart soil as substrate, smart soil production in climate-smart urban farming precinct, enhanced nutrient managing and releasing soil.

In the next step, for the activities categorised in this way, we made a comparative quantitative analysis. We presented the results of the research on maps developed for each city. Finally, we developed a summary map for 44 large Polish cities that shows quantitative data of planned and implemented NbSs in each category. For the sake of legibility of the graphic record, we singled out the area of the Silesian province from the summary map, which included up to 16 cities with urban adaptation plans. Although the obtained results may be subject to errors due to the lack of access to all sources, we assumed that the collected data can be representative to identify changes in the spaces of Polish cities. We used the conclusions obtained to identify recommendations for including NbSs in adaptive development policies carried out at the local level, increasing protection against the harmful effects of climate change, and introducing sustainable lifestyles in cities.

3. Results

3.1. NbS for Polish Urban Areas

Among the adaptation activities included in urban climate policy, a NbS plays a special role. Analysing the distribution of planned and implemented NbSs in the spaces of 44 large Polish cities, we found that their location in different areas depends on the category and type of action and the local conditions of individual cities. Re-naturing urbanisation most often includes the strict centre of cities (480 of 851 completed activities—56.4%, 118 of 418 planned activities—28.2%). A small exception is the city of Krakow (Figure 1), which, due to its holistic and systemic approach and in-depth planning analyses, focusses on implementing changes covering the entire city area or the vast majority of it. Activities in this area, on the one hand, are of a general nature and refer to nurturing, creation, and protection activities related to green areas in the city; on the other hand, they refer to specific places: streets, squares, and parks.

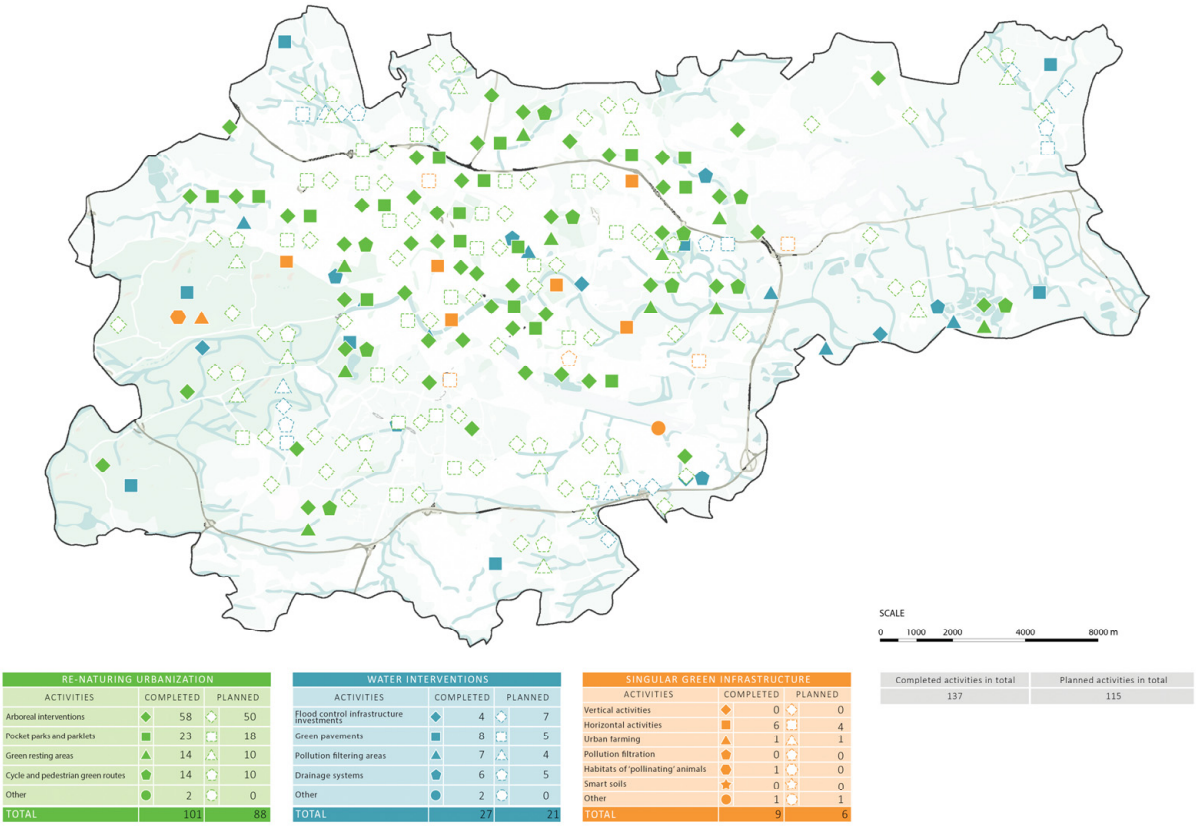

Figure 1. Distribution of completed and planned NbSs in Krakow. Adapted with permission from [42]. 2023, P. Białas.

Water interventions usually refer to places prone to flooding and are located near rivers and reservoirs (176 of 350 completed activities—50.3% and 86 of 126 planned activities—68.3%). The remaining solutions are implemented in various locations and usually result from the implementation of sustainable rainwater management policies.

In singular green infrastructure activities (107 planned and 329 completed), we did not note standardised rules for their placement in specific urban spaces. Most often, solutions of this type are deployed in locations individually identified in each city, depending on the conditions and organisational and financial tools assigned to each initiative.

During urban greening, city authorities, in their development strategies and adaptation plans, focus on increasing the resilience of public spaces by planting trees (293 of 851 completed activities—34.4% and 159 of 418 planned activities—38%). Furthermore, a frequently completed and planned activity in Polish cities is the nurturing, revitalisation, and establishment of urban recreational and leisure areas (272 of 851 completed activities—32% and 119 of 418 planned activities—28.5%). Half of these cities decided to create new public spaces in the form of pocket parks or parklets (129 of 851 completed projects—15.2% and 61 of 418 planned activities—14.6%). The least number of urban greening activities concern green walking and cycling paths (121 of 851 completed activities—14.2% and 59 of 418 planned activities—14.1%) (Figure 2).

Figure 2. Diagram of completed and planned NbSs in the category of re-naturing urbanisation; own study based on [42].

The leading city in terms of completed and planned urban greening activities is Krakow (101 completed activities and 88 planned, for a total of 189). Distant from Krakow, but still with a large number of realisations, are cities such as Szczecin (42), Slupsk (37), Walbrzych (37), Ruda Slaska (34), and Tychy (31). The figures for planned activities are arranged almost analogously. In this regard, in addition to Krakow, again, such cities as Szczecin (31) and Slupsk (26), as well as Bytom (16), Poznan (16), and Chorzow (15), are leading (Figure 3).

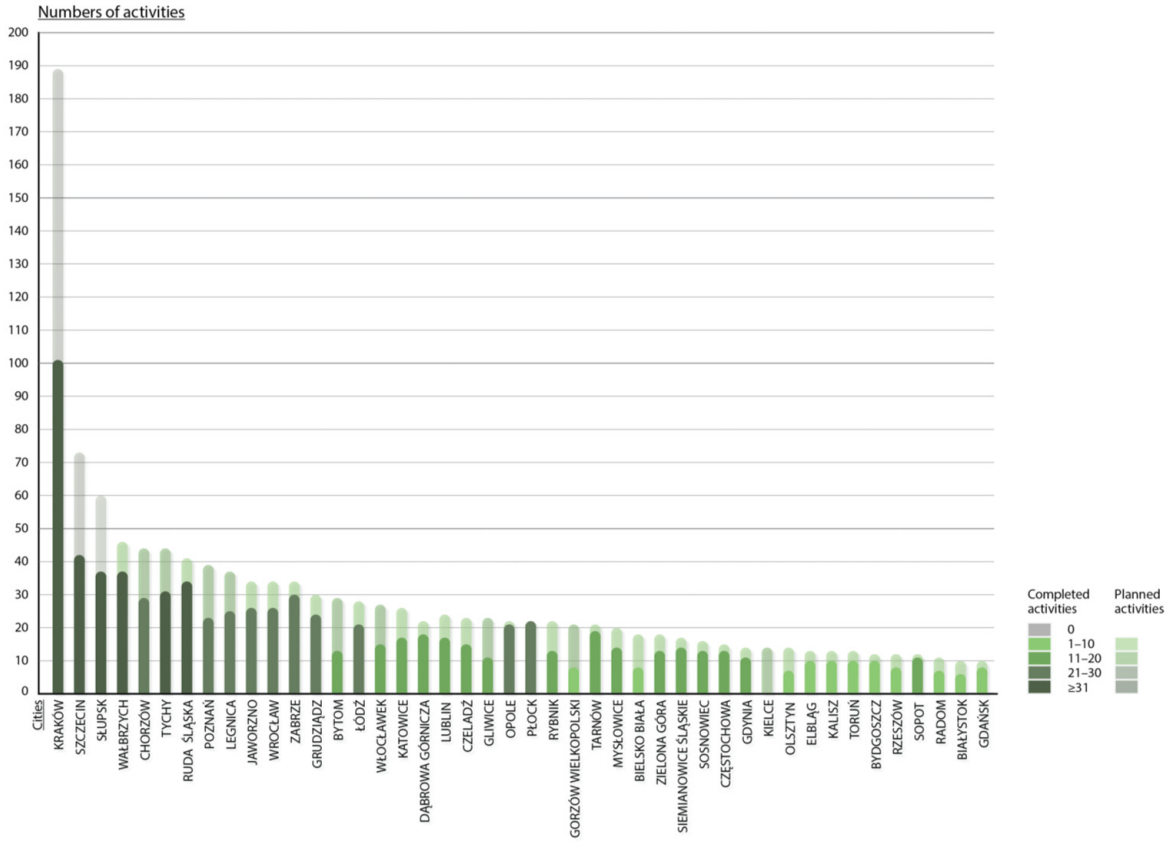

Figure 3. NbSs in the category of re-naturing urbanisation, completed and planned in 44 large Polish cities; own study based on [42].

The NbS analysis of water interventions showed that the largest number of activities in Polish cities were completed and planned for systemic drainage activities (113 of 350 activities completed—32.2% and 32 of 126 activities planned—25.4%) and flood pro-

tection (81 of 350 activities completed—23.1% and 48 of 126 activities planned—38.1%). Among water interventions, activities completed that involve the introduction of permeable surfaces can be distinguished (89 of 350 activities completed—25.4%). The least importance was given to areas of activities related to pollution filtering (33 of 350 activities completed—9.4% and 13 of 126 activities planned—10.3%) (Figure 4).

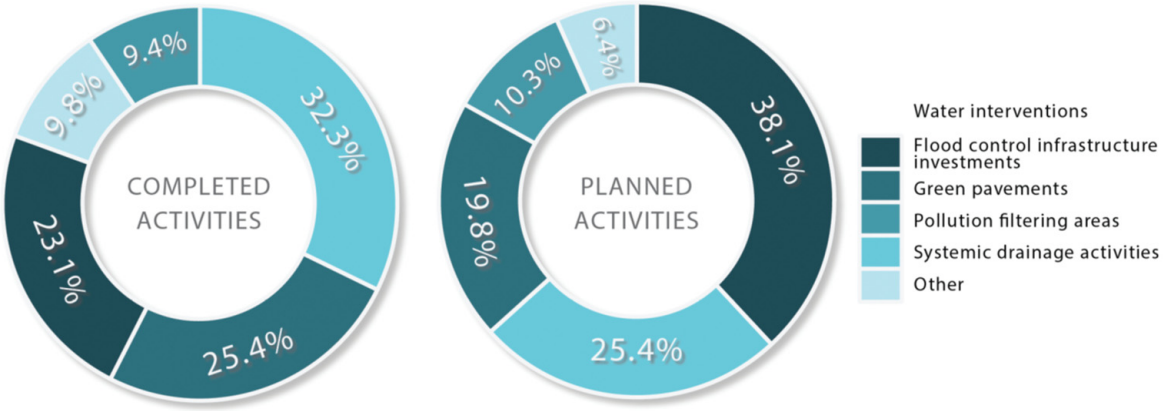

Figure 4. Diagram of the completed and planned NbSs in the category of water interventions; own study based on [42].

The city that stands out in terms of completed and planned NbSs from water intervention is, again, Krakow (27 completed activities and 21 planned, for a total of 48). In terms of the realisations themselves, three cities lead the way: Bydgoszcz (28), closely followed by the already mentioned Kraków (27), then Wrocław (25), and just behind them with a slightly lower number of activities, but still in the lead: Lodz (19) and Walbrzych (17). Regarding planned activities, Krakow (21) tops the list, followed closely by Slupsk (15) and Szczecin (13). The rest of the cities have planned fewer than 10 activities (Figure 5).

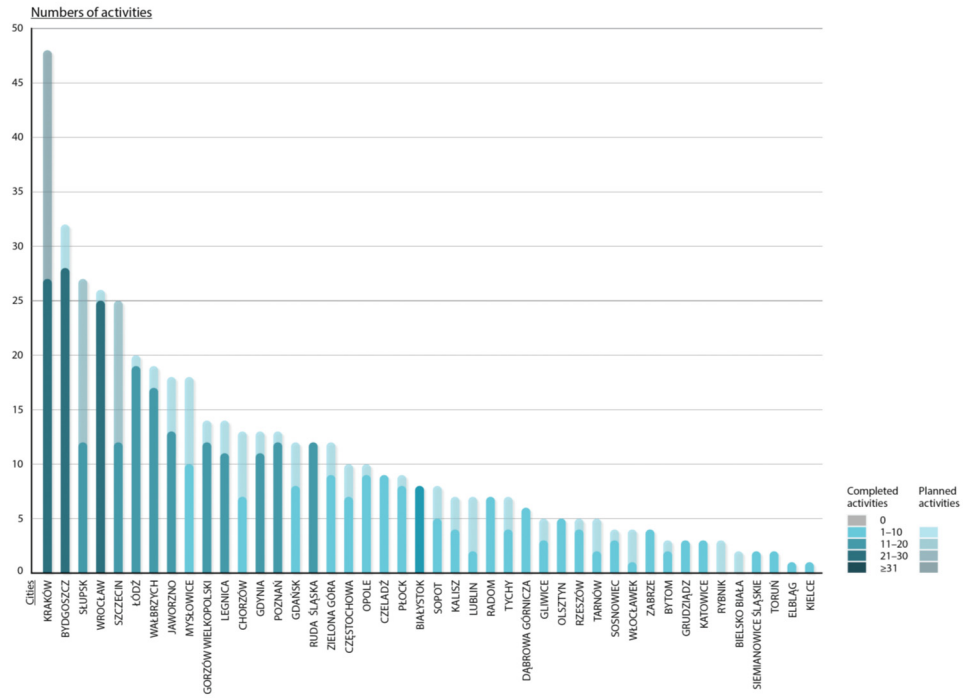

Figure 5. NbSs in the category of water intervention, completed and planned in 44 large Polish cities; own study based on [42].

In the category of singular green infrastructure activities in Polish cities, local authorities focused on horizontal activities: green roofs, canopies, shade structures, etc. (71 of

329 activities completed—21.6% and 47 of 107 activities planned—43.9%). Vertical activities, such as green walls, vertical gardens, and partitioning structures, although less frequently planned (18 of 107 activities planned—16.8%), come close to horizontal activities in number of realisations (52 of 329 activities realised—15.8%). Urban farming and pollution filtration activities are planned sporadically (8 of 107 planned activities—7.5%). Slightly more importance, though still insignificant, is given to the planning of habitats for pollinating animals (14 of 107 planned actions—13.1%). It was noted that no activities were planned to introduce smart soils. Among the point activities implemented, a significant group of NbSs could not be classified in any of the above categories (54 of 329 activities completed—16.4%). This group includes, for example, anti-smog programmes (Figure 6).

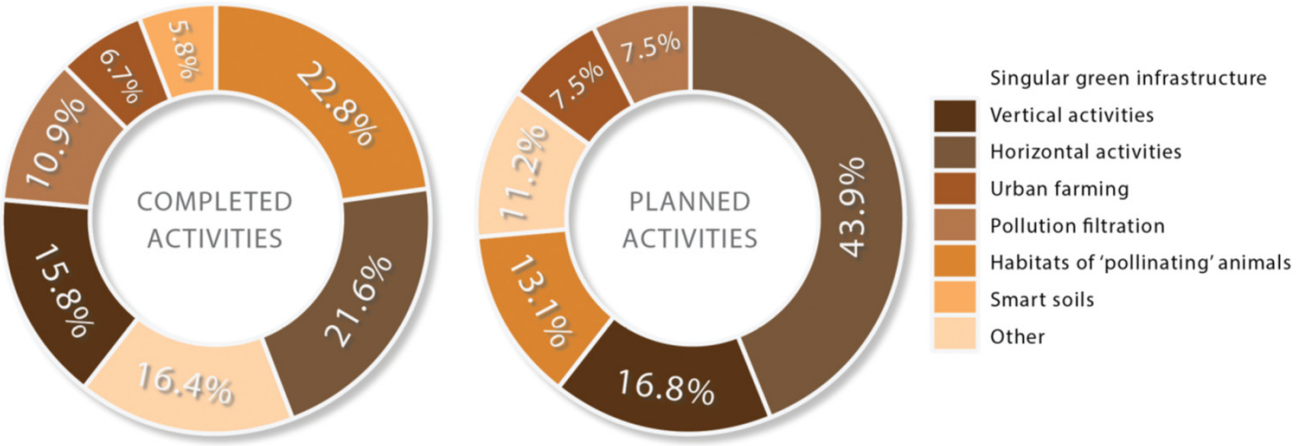

Figure 6. Diagram of completed and planned NbSs in the category of singular green infrastructure; own study based on [42].

The city that stands out in the category of scoring green infrastructure activities is Lodz, which, despite having only realised activities (0 planned), was ranked highest (37). An identical situation also appeared in Czestochowa, ranked second (30 completed and 0 planned). Cities that were further ranked were Wroclaw (15), Slupsk (14), Bialystok (13), Sosnowiec (13), Szczecin (12), and Bydgoszcz (12). In addition, Slupsk and Szczecin have the highest number of planned NbSs nationwide (15 and 14, respectively). The remaining 42 cities have planned far fewer (fewer than 10). The only city that has no implementations and plans for NbS development in this category is Bytom (0 planned activities and 0 completed activities) (Figure 7).

3.2. Comparative Study of the Use of NbS in the Scale of Poland

NbS research has been defined in three categories: re-naturing urbanisation, water interventions, and singular green infrastructure. This allowed the identification and benchmarking of implemented and planned solutions applied in the 44 large Polish cities in years 2017–2023 (Figure 8).

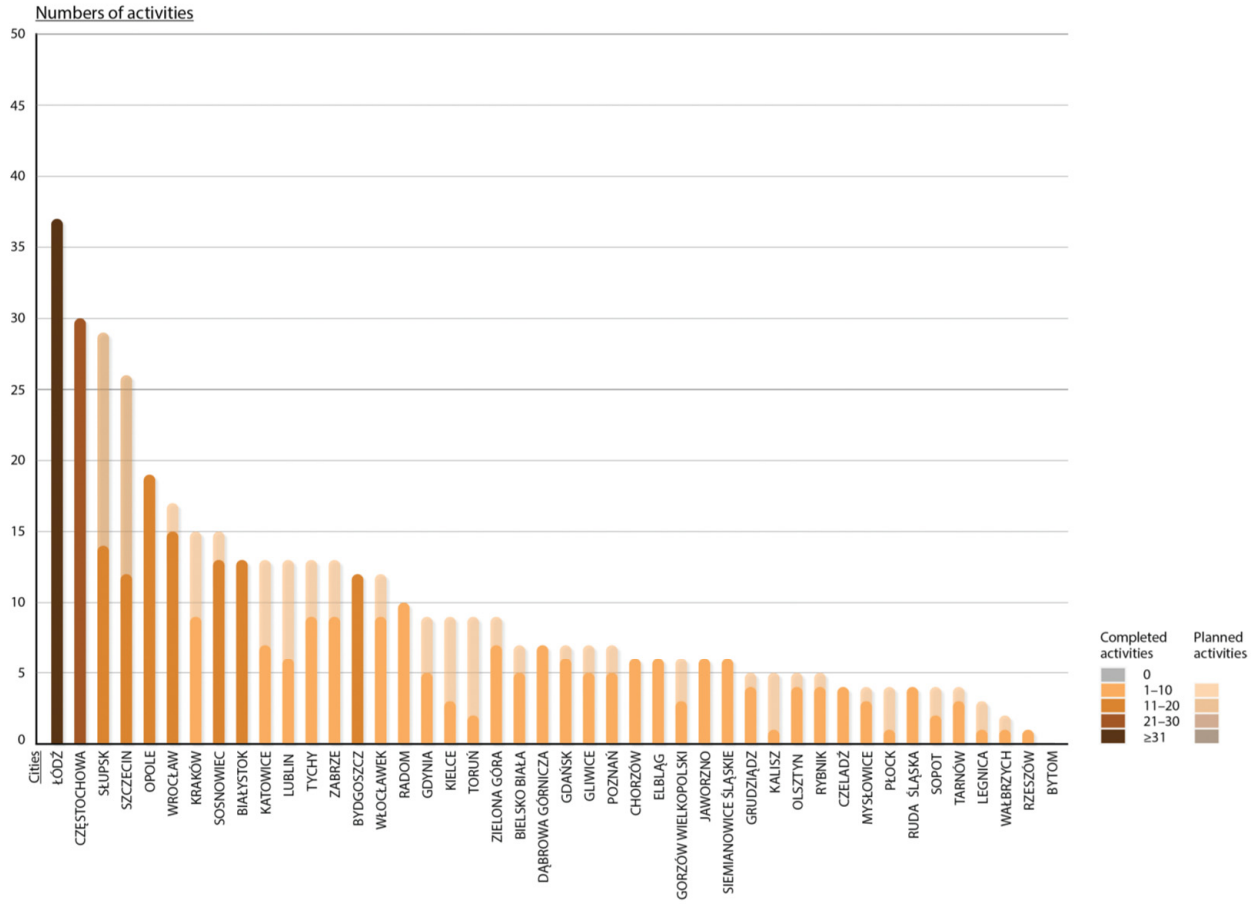

Figure 7. NbSs in the category of singular green infrastructure, completed and planned in 44 large Polish cities; own study based on [42].

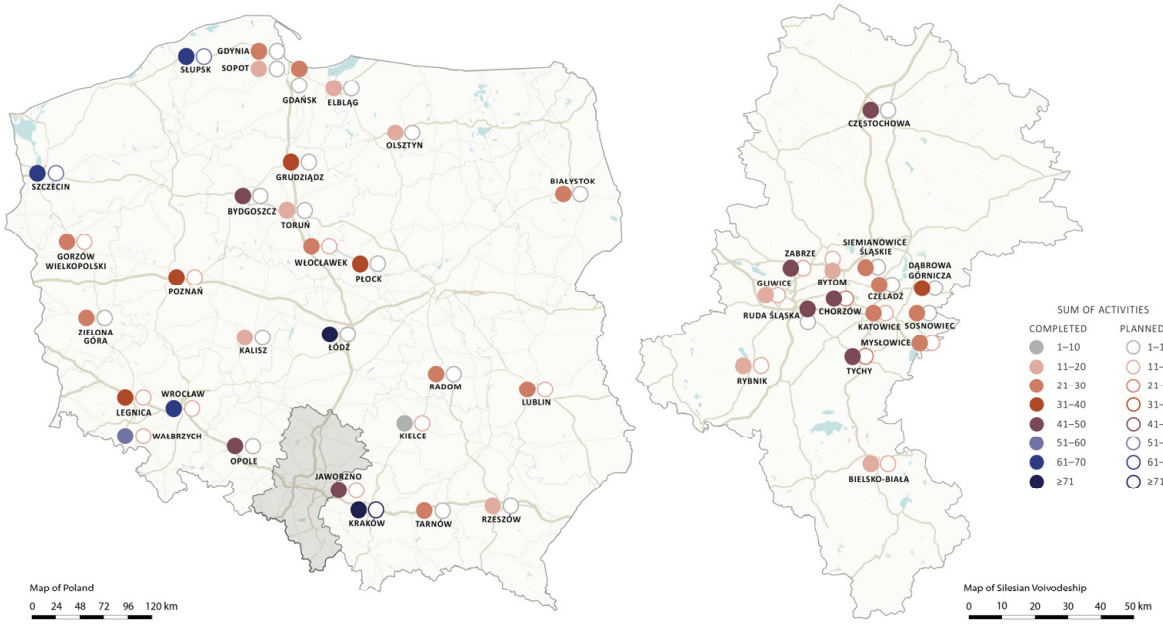

Figure 8. Map showing quantitative data of all completed and planned NbSs on a national scale with the distinction of Silesian Voivodeship; own study based on [42].

Based on the collected data, we determined the relationships between the planned and implemented interventions. The number of NbSs planned for all Polish cities sur-

veyed is (651), while the number of NbSs implemented is more than double, (1530). On the one hand, this may indicate the effectiveness of the development policy implemented in cities, but on the other hand, it may also indicate the weakness of planning and strategic tools. The results of the obtained data made it also possible to determine the number of NbSs in each category. Within the framework 'renaturing urbanisation', a total of (418—64.2%) interventions are planned and (851—55.6%) interventions were implemented. Within 'water interventions', (126—19.4%) interventions are planned and (350—22.9%) interventions were implemented. In the category of 'singular green infrastructure', (107—16.4%) interventions are planned and (329—21.5%) interventions were carried out. These data indicate a significant dominance of 'greening of urban space' interventions. The total number of planned and implemented interventions in this category (1269) exceeds the total sum of interventions in the other two categories (476 and 436) by almost three times. These differences may result from the priorities and strategic goals adopted in the city documents and the ability to raise funds for the implementation of individual interventions. Differences may also be caused by specific local conditions and characteristics that affect the degree of urban development, determining the vulnerability of urban spaces to climate change (Figure 9).

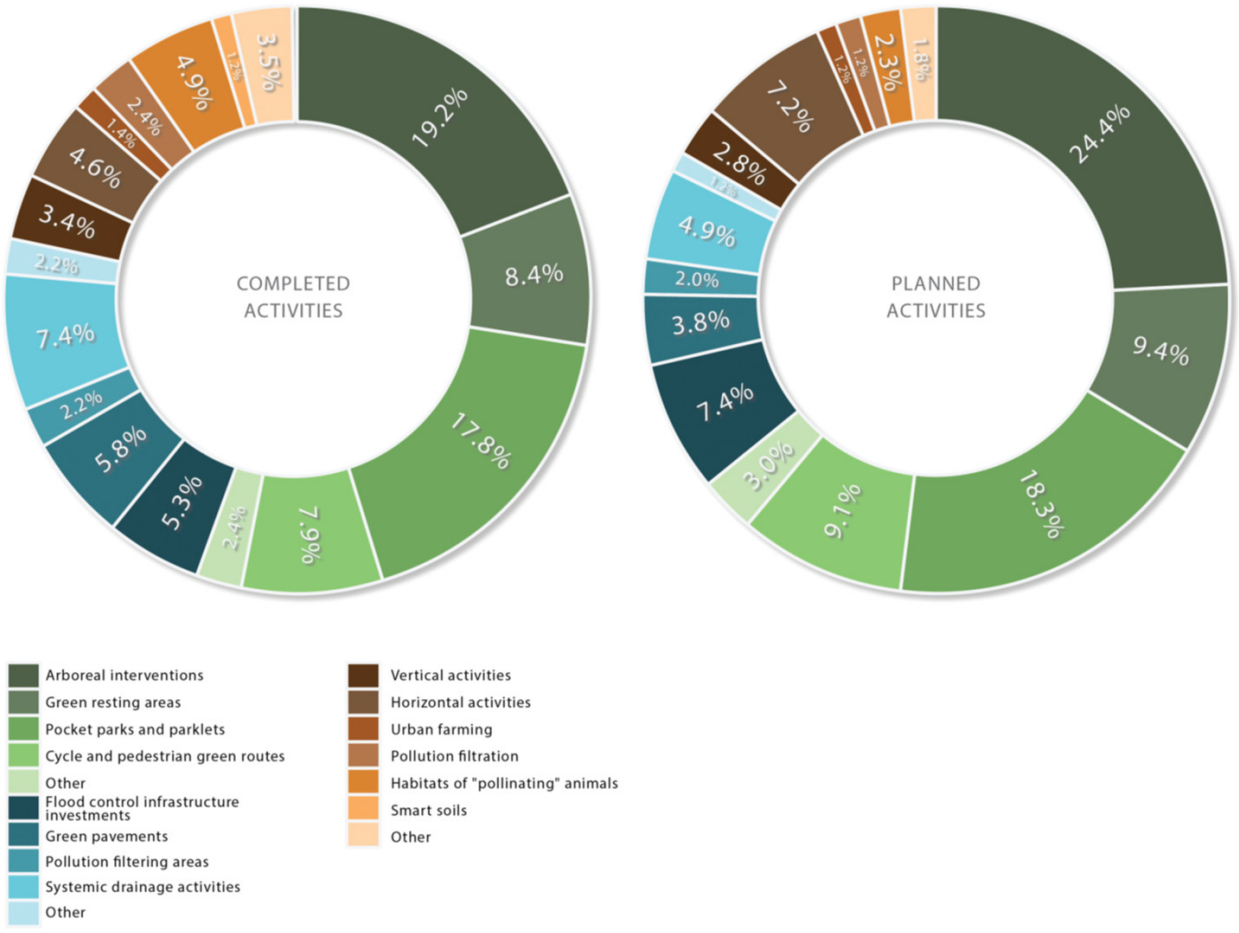

Figure 9. Diagram of completed and planned NbSs in all categories; own study based on [42].

The research carried out has also allowed us to compare different cities and identify those that take the most holistic and least holistic approach to NbS planning and implementation (Figure 10).

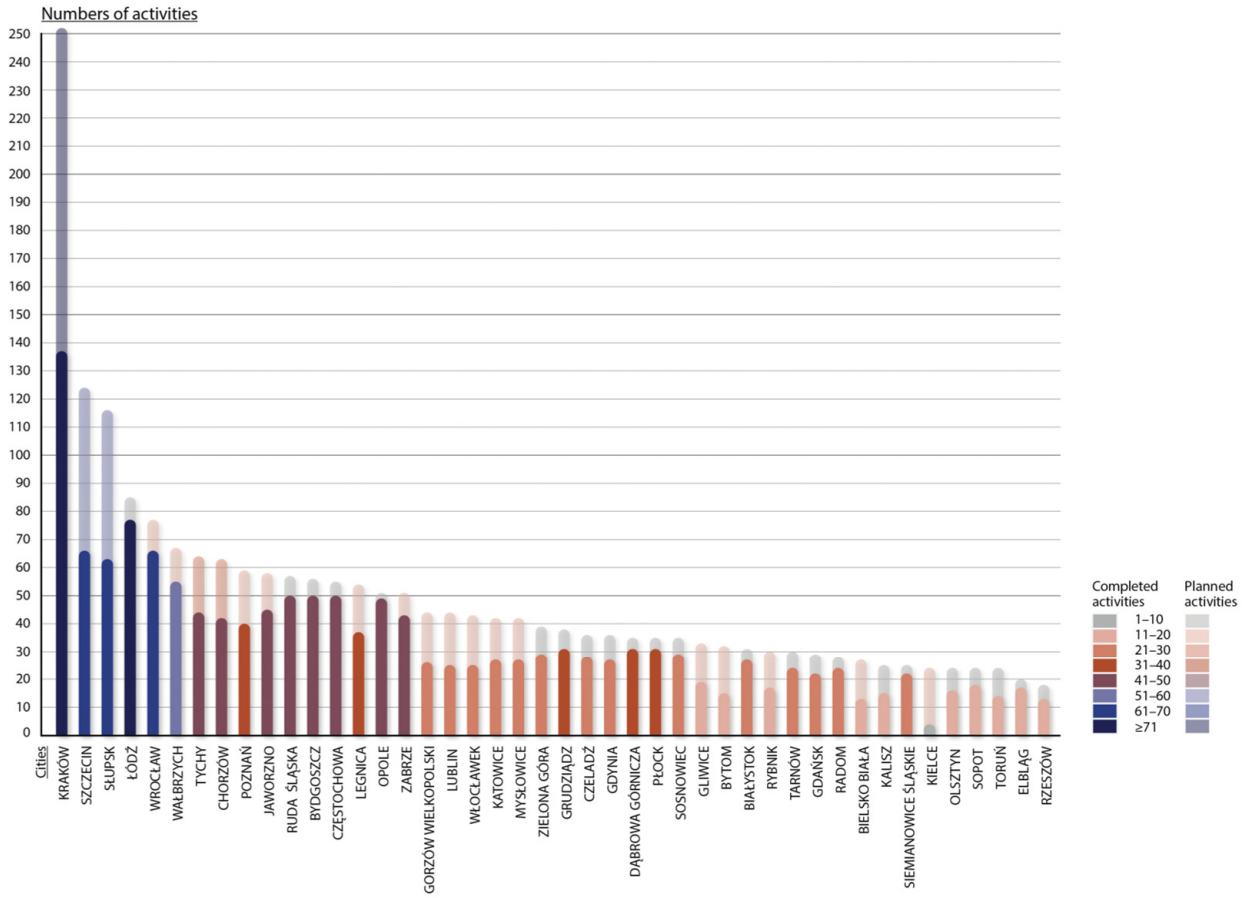

Figure 10. Diagram of quantitative data of all completed and planned NbSs in 44 large Polish cities; own study based on [42].

In 41 of the 44 large Polish cities, the authors noticed an advantage of already implemented interventions over those planned. The exceptions are three cities where the proportions were reversed: Bytom: (17) planned interventions and (15) implemented; Bielsko-Biala: (15) planned interventions and (13) implemented; and Kielce: (20) planned interventions and (4) implemented. The city of Kielce was weakest in terms of NbSs implementation nationally. The city that stands out in Poland is Krakow. This city has (115) planned interventions and (137) implemented interventions. Other significant cities in terms of NbSs are also: Szczecin: (58) planned and (66) implemented interventions; Slupsk: (53) planned and (63) implemented interventions; Lodz: (8) planned but (77) implemented interventions; and Wroclaw: (11) planned and (66) implemented interventions. Most of the cities with the highest number of implemented and planned results are the leading cities in the region or provincial capitals.

In assigning NbSs to categories and types of activities closely related to the objectives of the URBAN GreenUP project, we observed that only a small part of the activities could not be assigned to any of these groups. We assigned individual planned and implemented in Polish cities, not included in the typology of the URBAN GreenUP project, to the 'other' groups in each category. In all categories together, the number of activities planned in the 'other' group (40) accounted for 6% of all planned NbSs, and the number of activities implemented in the 'other' group (124) accounted for 8% of all implemented NbSs. Among them were mainly municipal projects and initiatives, implemented from civic budgets profiled towards ecological and environmental public tasks. These included activities such as urban sunflower fields, green relaxation zones, green bus stops, green courtyards, small recreational glades, urban waterfront beaches, picnic parks, lavender nooks, hedgehog houses, and bird nesting boxes Fewer large urban investments were made. We can count

among them the restoration of coastal dunes, projects for new legal forms of protection of natural values, or revitalisations of anthropogenic water bodies.

Among the adaptation activities introducing NbSs in urban spaces, only a few are innovative. Our research shows that out of 44 large Polish cities, innovative interventions can only be found in the area of singular green infrastructure (6 measures in Ruda Slaska, Tarnow, Gliwice, and Rybnik). They relate to vertical interventions (1 implemented intervention), horizontal interventions (1 planned intervention and 1 implemented intervention), pollution filtration (2 planned interventions), and smart soils (1 implemented intervention). An interesting example is the revitalisation of the 'Mount Antonia' post-zinc tailings pile and the reclamation and remediation of the former Orzegow Coke Plant site in Ruda Slaska, using the phytostablisation process.

One of the few planned NbSs that takes energy transition into account is the plan to build a photovoltaic farm in Rybnik. The basis for taking this action is the implementation of the 'National Action Plan on Energy and Renewable Sources'. The investment, which will include 5400 solar panels, 17 grid inverters, a 2500 kVa transformer station, and a switchgear, is expected to produce electricity with a total capacity of 2.5 MW. The assumed environmental effect of the project will be a decrease in greenhouse gas emissions by 1636 tons of carbon dioxide equivalent and an increase in RES electricity production by 2158 MWhe/year [43]. The Tarnow authorities have also decided to invest in a photovoltaic farm.

One of the important NbSs is a plan created in 2022 to build the 'Green Energy Centre' in Rybnik. It will be a state-of-the-art centre for circular waste management, as well as for the extraction of heat, electricity, and hydrogen from waste, in a way that meets the goals of achieving recycling and preparation for reuse levels. The thermal waste conversion facility will manage waste in a safe and environmentally friendly way and, as a result, it will provide heat and electricity for its own installations and for the production of residents, as well as for hydrogen (propulsion for buses) [44].

All the mentioned examples represent only a small fraction of all NbSs analysed in Polish cities (0.23%) and indicate untapped potential in this area.

4. Discussion

4.1. The Use of NbSs in the Context of the URBAN GreenUP Project

The quantitative analysis of the obtained data allowed us to identify NbSs in 44 large Polish cities and consequently diagnose their contribution to local adaptation efforts. According to the International Union for the Conservation of Nature (IUCN), NbSs are defined as: 'actions to protect, sustainably manage and restore natural and modified ecosystems in ways that address societal challenges effectively and adaptively, to provide both human well-being and biodiversity benefits' [5]. We took a closer look at the criteria by which the analysed activities can be categorised as NbSs: (1) NbSs effectively address societal challenges, (2) the design of NbSs is informed by the scale, (3) NbSs result in a net gain to biodiversity and ecosystem integrity, (4) NbSs are economically viable, (5) NbSs are based on inclusive, transparent, and empowered governance processes, (6) NbSs equitably balance trade-offs between the achievement of their primary goal(s) and the continued provision of multiple benefits, (7) NbSs are managed adaptively, based on evidence, and (8) NbSs are sustainable and mainstreamed within an appropriate jurisdictional context [5]. Albert, Spangenberg, and Schröter used other criteria [4]. An assessment of the degree of implementation of individual NbSs is not possible with the research method adopted in the article. However, the awareness of the criteria and the role of NbSs in adaptation activities allow us to assess the directions of the development policy adopted by Polish cities, aimed at an integrated approach to sustainable development and urban resilience. The inclusion of NbSs in urban adaptation plans is kind of equivalent to the provisions in European renaturing urban plans implemented in URBAN GreenUP [7].

We agree with Cortinovis and Geneletti [45] that incorporating ecosystem services into spatial planning and urban design is essential for sustainable urban development.

The analysis of NbSs in three mentioned categories of interventions has shown us that Polish cities are gradually beginning to focus on solutions that can provide broadly understood ecosystem services that contribute to the adaptation of urban spaces to climate change. The local governments of Polish cities, such as those of the cities in the URBAN GreenUP project, have recognised the potential of NbSs to solve problems such as air pollution, the effect of the urban heat island, threats from floods, degradation of urban areas, or loss of natural areas. When comparing the effects of planned and implemented interventions, we observed a disparity between cities in their approaches to individual solutions. In many cities, planned and implemented measures often cannot be qualified as systematic and properly organised. The ability to implement NbSs is a result of a city's level of economic development; governance; complementarity of planning tools; and financial, human, institutional, infrastructure, and knowledge resources. We agree with Bowler et al. [46] that urban greening is an effective strategy to adapt cities to climate change. Almost all Polish cities have recognised the greening of urban spaces as an important adaptive measure and one that requires rapid implementation. They focused mainly on tree planting and the creation and revitalisation of urban recreational and leisure areas. In some of the cities of the URBAN GreenUP project (Izmir, Liverpool, and Valladolid), the most frequently proposed solutions were green routes, arboreal interventions, resting areas, and carbon capture solutions. Planned interventions are expected to contribute to the reduction in equivalent CO_2 emissions, creation of new green and resting surfaces, reduction in allergies by 50%, reduction in ambient temperature by 2–4 °C, reduction in gas emissions coming from vehicles, reduction in the ambient temperature by 2 °C during summer, and increase in biodiversity [47–49].

Most Polish cities have undertaken the implementation of multiple investments in the area of sustainable water management (most often in the field of flood protection and systemic drainage measures) and singular green infrastructure interventions (green roofs, walls, gardens shade structures, etc.). In Izmir, Liverpool, and Valladolid, the focus is mostly on the following: Sustainable Urban Drainage Systems (SUDSs), flood actions, water treatment, green pavements, and rain gardens in terms of water interventions; cycle pedestrian infrastructures, green roofs, green walls, smart soils, biochar, pollinators, pollutants filter, and urban farming in terms of singular green infrastructure interventions. Such interventions are expected to improve rainwater management, protect urban land and citizens from serious flood damage, prevent flash floods and increase water retention capacity, reduce carbon dioxide emissions, improve air quality, reduce the heat island effect by 1.5 °C, reduce ambient temperature by 2 to 4 °C, and promote ecological awareness among citizens and improve their health [47–49].

Only a handful of Polish cities have taken on the task of implementing innovative NbSs. Equally few cities have recognised the opportunity to link NbSs with the possibility of using renewable energy in the process (photovoltaic farms, Green Energy Centre in Rybnik and Tarnow, and microbial fuel cell technology in an electro wetland in Valladolid). Increasing the number of such links could contribute to the more efficient management of resources and urban areas and could also provide economic benefits in the form of new jobs in the green sector. In conclusion, we consider the study results to be important evidence of the growing role of NbSs in sustainable urban development and in adapting urban spaces to climate change.

We considered selected NbS aspects as a positive contribution to:

- Reducing CO_2 emissions and reducing air pollution;
- Reducing the impact of urban heat islands;
- Increasing biodiversity;
- Supporting the process of shaping the city's ecological system;
- Shaping recreation and leisure spaces;
- Increasing land and property values;
- Reducing stress levels and increasing positive impact on the health and quality of life of residents.

Thanks to their experience, leading Polish and European cities, in terms of planning and implementing NbSs, can encourage other cities to complement urban adaptation strategies with the use of NbSs to shape attractive and resilient spaces in the city.

4.2. Further Research Directions

The data obtained during our research can form the basis for further quantitative and qualitative studies defined for different types of NbSs in selected cities. It can also serve as a starting point for assessing the impact of NbSs on urban space and the quality of life of residents.

In each Polish city, the effects of NbSs can be measured in terms of urban services and quality of life. The results can be used to develop a consistent approach to designing and monitoring different types of solutions. One way to measuring the effects of NbSs is to use the indicators of the 'International Standard ISO 37120:2014 Sustainable development of communities—Indicators for city services and quality of life' and its Polish counterpart PN-ISO 37120 [50]. Among other urban indicators for the purpose of further research, it would be important to measure the core indicators in the area of energy. These include the percentage of energy obtained from renewable sources in the context of total urban energy consumption. In the environment, it is possible to measure the concentrations of fine particulate matter PM2.5 and PM10, or greenhouse gas emissions measured in tons per capita. In the area of urban planning, indicators of green areas (in hectares) per 100,000 residents would be useful for further research. It would also be important to measure auxiliary indicators: in terms of the environment—determining the change in the number of native species; in terms of recreation—the data number of square metres of public (indoor or outdoor) recreational space per capita; in terms of urban planning—the annual number of planted trees per 100,000 residents. The conclusions of the obtained data could form the basis for the integration of NbSs into municipal climate strategies. They would also make it possible to test the effective use of NbSs in the management of energy generation, the reduction in CO_2, and air pollution. Ultimately, they could also encourage cities to update the strategic planning documents for subsequent planning periods (including UAPs).

5. Conclusions

The NbSs identified in Polish cities indicate that their potential has not yet been fully realised. The adaptation policies and strategies of Polish cities are largely based on general planning provisions and actions that require a more systemic approach.

The focus of local authorities on selected NbSs, instead of the holistic approach, prevents their effective use in the process of adapting urban spaces to climate change. The main shortcomings in this regard are as follows:

- Lack of a holistic approach to the full range of ecosystem services that NbSs bring;
- A small share of innovative solutions, based on new technologies;
- A small share of solutions that generate clean energy;
- Insufficient knowledge, lack of understanding, and organisational and financial unpreparedness for planning and implementing NbSs among local governments;
- Low awareness and lack of public education.

The identification of problems and shortcomings in the inclusion of NbSs in local policies could serve as a guideline for the better organisation of municipal policies and greater complementarity in the use of NbSs. Taking into account the above statements, we recommend the further introduction of NbSs as actions that complement adaptation activities and improve a sustainable urban lifestyle. We recommend the introduction of the following measures:

- Reviewing and updating of urban adaptation plans, programmes, and strategies with regard to the application of NbSs;
- Developing planning and urban planning guidelines for shaping urban spaces using NbSs;

- Linking systemic actions that take into account NbSs, with singular actions, expanding the scope of applied solutions;
- Investing in cutting-edge research and innovation;
- Realising more efficient use of energy and resources in NbSs;
- Building systems for collecting data and monitoring implemented solutions;
- Conducting educational and promotional activities;
- Implementing new forms of organisation and management to NbSs;
- Securing adequate financial resources in city budgets;
- Strengthening the creativity of local authorities and the participation of residents.

In summary, embedding NbSs in local policies is crucial and can become the basis for conscious planning and the implementation of coherent, effective, and sustainable NbSs in cities, complementary to adaptation policies, bringing maximum benefits to both the built and natural environment and the urban community.

Author Contributions: Conceptualization, A.P.; methodology, A.P.; software, A.P.; validation, A.P., D.B., D.D., M.M., and N.S.; formal analysis, A.P., D.B., D.D., M.M., and N.S.; investigation, A.P., D.B., D.D., M.M., and N.S.; resources, A.P., D.B., D.D., M.M., and N.S.; data curation, A.P., D.B., D.D., M.M., and N.S.; writing—original draft preparation, A.P., D.B., D.D., M.M., and N.S.; writing—review and editing, A.P., D.B., D.D., M.M., and N.S.; visualization, N.S.; supervision, A.P.; project administration, A.P.; funding acquisition, A.P. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by Silesian University of Technology.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Mumford, L. *The City in History: Its Origins, Its Transformations, and Its Prospects*; Harcourt, Brace and World: New York, NY, USA, 1961.
2. Kostof, S. *The City Shaped: Urban Patterns and Meanings Through History*; A Bulfinch Press Book: Belfast, UK; Little, Brown and Company: Boston, MA, USA, 1999.
3. Pancewicz, A. Planning and strategic tools for adapting urban areas to climate change in Poland. *Archit. Civ. Eng. Environ.* **2021**, *4*, 31–44. [CrossRef]
4. Albert, C.; Spangenberg, J.H.; Schröter, B. Nature-based solutions: Criteria. *Nature* **2017**, *543*, 315. [CrossRef] [PubMed]
5. Eggermont, H.; Balian, E.; Azevedo, J.M.N.; Beumer, V.; Brodin, T.; Claudet, J.; Fady, B.; Grube, M.; Keune, H.; Lamarque, P.; et al. Nature-based Solutions: New Influence for Environmental Management and Research in Europe. *GAIA Ecol. Perspect. Sci. Soc.* **2015**, *24*, 243–248. [CrossRef]
6. IUCN. *Global Standard for Nature-Based Solutions: A User-Friendly Framework for the Verification, Design and Scaling up of NbS*, 1st ed.; IUCN: Gland, Switzerland, 2020. [CrossRef]
7. URBAN GreenUP. European Union's Horizon 2020 Programme. Available online: https://www.urbangreenup.eu/ (accessed on 15 March 2023).
8. World Bank. *Biodiversity, Climate Change, and Adaptation: Nature-Based Solutions from the World Bank Portfolio*; World Bank: Washington, DC, USA, 2008. Available online: http://hdl.handle.net/10986/6216 (accessed on 21 April 2023).
9. European Commission, Directorate-General for Research and Innovation. Towards an EU Research and Innovation Policy Agenda for Nature-Based Solutions & Re-Naturing Cities: Final Report of the Horizon 2020 Expert Group on 'Nature-Based Solutions and Re-Naturing Cities': (Full Version); Publications Office. 2015. Available online: https://data.europa.eu/doi/10.2777/479582 (accessed on 21 April 2023).
10. European Commission, Directorate-General for Research and Innovation; Bulkeley, H.; Naumann, S.; Vojinovic, Z.; Calfapietra, C.; Whiteoak, K.; Freitas, T.; Vandewoestijne, S.; Wild, T. *Nature-Based Solutions: State of the Art in EU-Funded Projects*; Freitas, T., Vandewoestijne, S., Wild, T., Eds.; Publications Office of the European Union: Luxembourg, 2020. Available online: https://data.europa.eu/doi/10.2777/236007 (accessed on 21 April 2023).
11. Zwierzchowska, I.; Fagiewicz, K.; Poniży, L.; Lupa, P.; Mizgajski, A. Introducing nature-based solutions into urban policy—facts and gaps. Case study of Poznań. *Land Use Policy* **2019**, *85*, 161–175. [CrossRef]
12. Albert, C.; Brillinger, M.; Guerrero, P.; Gottwald, S.; Henze, J.; Schmidt, S.; Ott, E.; Schröter, B. Planning nature-based solutions: Principles, steps, and insights. *AMBIO* **2020**, *50*, 1446–1461. [CrossRef]
13. Mahmoud, I.; Morello, E.; Lemes de Oliveira, F.; Geneletti, D. *Nature-Based Solutions for Sustainable Urban Planning Greening Cities, Shaping Cities*; Springer: Berlin/Heidelberg, Germany, 2022.

14. Lafortezza, R.; Chen, J.; van den Bosch, C.K.; Randrup, T.B. Nature-based solutions for resilient landscapes and cities. *Environ. Res.* **2018**, *165*, 431–441. [CrossRef]
15. European Commission, Directorate-General for Research and Innovation; Dumitru, A.; Wendling, L. *Evaluating the Impact of Nature-Based Solutions: Appendix of Methods*; Dumitru, A., Wendling, L., Eds.; Publications Office of the European Union: Luxembourg, 2021. Available online: https://data.europa.eu/doi/10.2777/11361 (accessed on 21 April 2023).
16. *Nature-Based Solutions in Europe: Policy, Knowledge and Practice for Climate Change Adaptation and Disaster Risk Reduction*; EEA Report No 1/2021; European Environment Agency: Copenhagen, Denmark, 2021.
17. Štrbac, S.; Kašanin-Grubin, M.; Pezo, L.; Stojić, N.; Lončar, B.; Ćurčić, L.; Pucarević, M. Green Infrastructure Designed through Nature-Based Solutions for Sustainable Urban Development. *Int. J. Environ. Res. Public Health* **2023**, *20*, 1102. [CrossRef]
18. Pochodyła, E.; Jaszczak, A.; Illes, J.; Kristianova, K.; Joklova, V. Analysis of green infrastructure and nature-based solutions in Warsaw—Selected aspects for planning urban space. *Acta Hortic. Regiotectuare* **2022**, *25*, 44–50. [CrossRef]
19. Giombini, V.; Thorn, J.P.R. Urban Green Spaces in a Post-Apartheid City: Challenges and Opportunities for Nature-based Solutions. In *Human-Nature Interactions*; Misiune, I., Depellegrin, D., Egarter Vigl, L., Eds.; Springer: Cham, Switzerland, 2022; pp. 207–219. [CrossRef]
20. Dige, G. *Green Infrastructure: Better Living through Nature-Based Solutions*; European Environment Agency: Copenhagen, Denmark, 2015.
21. Vogel, S.; Monsarrat, S.; Pasgaard, M.; Buitenwerf, R.; Custock, A.C.; Ceauşu, S.; Li, W.; Gordon, C.E.; Jarvie, S.; Mata, J.; et al. A multi-disciplinary perspective to nuance the narrative of tree planting as a nature-based solution. *SocArXiv* **2021**. [CrossRef]
22. Widelska, E.; Sowińska-Świerkosz, B.; Walczak, W. Natural Water Reservoirs as an Example of Effective Nature-Based Solutions (NBS). In *Limnology-The Importance of Monitoring and Correlations of Lentic and Lotic Waters*; IntechOpen: London, UK, 2023. [CrossRef]
23. Bunclark, L.; Hernández, I.M.D.L.V. Scientific Mapping of Research on Nature-based Solutions for Sustainable Water Management. *Water Resour. Manag.* **2022**, *36*, 4499–4516. [CrossRef]
24. Veloza, M.A.M.; Dadati, M.C.; Giordano, R.; Savio, L. Water security: The "new normality" of informal settlements. Nature-Based Solutions as sustainable mitigation and adaptation strategies. *Vitr. Int. J. Arch. Technol. Sustain.* **2022**, *7*, 62–77. [CrossRef]
25. Beceiro, P.; Brito, R.S.; Galvão, A. Nature-based solutions for water management: Insights to assess the contribution to urban resilience. *Blue-Green Syst.* **2022**, *4*, 108–134. [CrossRef]
26. Sušnik, J.; Masia, S.; Kravčík, M.; Pokorný, J.; Hesslerová, P. Costs and benefits of landscape-based water retention measures as nature-based solutions to mitigating climate impacts in eastern Germany, Czech Republic, and Slovakia. *Land Degrad. Dev.* **2022**, *33*, 3074–3087. [CrossRef]
27. Kolokotsa, D.; Lilli, A.; Lilli, M.A.; Nikolaidis, N.P. On the impact of nature-based solutions on citizens' health & well being. *Energy Build.* **2020**, *229*, 110527. [CrossRef]
28. Frantzeskaki, N.; McPhearson, T. Mainstream Nature-Based Solutions for Urban Climate Resilience. *Bioscience* **2021**, *72*, 113–115. [CrossRef]
29. Elmqvist, T.; Andersson, E.; Frantzeskaki, N.; McPhearson, T.; Olsson, P.; Gaffney, O.; Takeuchi, K.; Folke, C. Sustainability and resilience for transformation in the urban century. *Nat. Sustain.* **2019**, *2*, 267–273. [CrossRef]
30. Kabisch, N.; Korn, H.; Stadler, J.; Bonn, A. (Eds.) Nature-based Solutions to Climate Change Adaptation in Urban Areas. Linkages between Science, Policy and Practice. In *Theory and Practice of Urban Sustainability Transitions*; Springer Open: Berlin/Heidelberg, Germany, 2017. Available online: https://link.springer.com/book/10.1007/978-3-319-56091-5 (accessed on 15 March 2023).
31. Pearlmutter, D.; Theochari, D.; Nehls, T.; Pinho, P.; Piro, P.; Korolova, A.; Papaefthimiou, S.; Mateo, M.C.G.; Calheiros, C.; Zluwa, I.; et al. Enhancing the circular economy with nature-based solutions in the built urban environment: Green building materials, systems and sites. *Blue-Green Syst.* **2019**, *2*, 46–72. [CrossRef]
32. Asl, S.R. Re-powering the Nature-Intensive Systems: Insights from Linking Nature-Based Solutions and Energy Transition. *Front. Sustain. Cities* **2022**, *4*, 860914. [CrossRef]
33. Girardin, C.A.J.; Jenkins, S.; Seddon, N.; Allen, M.; Lewis, S.L.; Wheeler, C.E.; Griscom, B.W.; Malhi, Y. Nature-based solutions can help cool the planet—If we act now. Analysis suggests that to limit global temperature rise, we must slash emissions and invest now to protect, manage and restore ecosystems and land for the future. *Nature* **2021**, *593*, 191–194. [CrossRef]
34. Shafique, M.; Luo, X.; Zuo, J. Photovoltaic-green roofs: A review of benefits, limitations, and trends. *Sol. Energy* **2020**, *202*, 485–497. [CrossRef]
35. Hakimizad, S.; Asl, S.R.; Ghiai, M.M. A Review on the Design Approaches Using Renewable Energies in Urban Parks. *Int. J. Renew. Energy Res.* **2015**, *5*, 686–693. [CrossRef]
36. Burney, J.; Phillips, S.; Lahl, J. Assessing the productivity and profitability of the Solar Market Garden. *Dev. Eng.* **2018**, *3*, 60–71. [CrossRef]
37. Raymond, C.M.; Frantzeskaki, N.; Kabisch, N.; Berry, P.; Breil, M.; Nita, M.R.; Geneletti, D.; Calfapietra, C. A framework for assessing and implementing the co-benefits of nature-based solutions in urban areas. *Environ. Sci. Policy* **2017**, *77*, 15–24. [CrossRef]
38. URBAN GreenUP—Solutions—Smart Soil Production in Climate-Smart Urban Farming Precinct. Available online: https://www.urbangreenup.eu/solutions/smart-soil-production-in-climate-smart-urban-farming-precinct.kl (accessed on 15 March 2023).

39. URBAN GreenUP—Solutions—Electro Wetland. Available online: https://www.urbangreenup.eu/solutions/electro-wetland.kl (accessed on 15 March 2023).
40. *Climate Change Adaptation Plans in 44 Polish Cities*; Summary Report; Ministry of the Environment: Warsaw, Poland, 2018. Available online: http://44mpa.pl/wp-content/uploads/2018/12/MPA_NET-ENG-20-12.pdf (accessed on 19 March 2023).
41. Building Urban Environmental Resilience—How Are Polish Cities Preparing for Climate Change? (Budując Miejską Odporność Środowiskową—Jak Polskie Miasta Przygotowują się na Zmiany Klimatu?). Available online: https://www.gov.pl/web/wuf11/budujac-miejska-odpornosc-srodowiskowa{-}{-}jak-polskie-miasta-przygotowuja-sie-na-zmiany-klimatu (accessed on 22 March 2023).
42. Pancewicz, A.; Białas, P. Silesian University of Technology, Gliwice, Poland. Seminar Papers of the First-Year Master's Students of the Faculty of Architecture at the Silesian University of Technology, Performed on the Subject: Renewal of Degraded Urban Landscape in the Academic Year 2022/2023. Unpublished work. 2023.
43. Photovoltaic Farm, Rybnik. Operational Program Infrastructure and Environment. Service of the Republic of Poland. Available online: https://www.gov.pl/web/nfosigw/inwestycja-oze-w-rybniku-dzieki-srodkom-poiis (accessed on 22 March 2023).
44. Subregional Green Energy Center, Rybnik. Available online: https://www.rybnik.eu/dla-mieszkancow/aktualnosci/aktualnosc/subregionalne-centrum-zielonej-energii (accessed on 2 April 2023).
45. Cortinovis, C.; Geneletti, D. Ecosystem services in urban plans: What is there, and what is still needed for better decisions. *Land Use Policy* **2018**, *70*, 298–312. [CrossRef]
46. Bowler, D.E.; Buyung-Ali, L.; Knight, T.M.; Pullin, A.S. Urban greening to cool towns and cities: A systematic review of the empirical evidence. *Landsc. Urban Plan.* **2010**, *97*, 147–155. [CrossRef]
47. New Strategy for Renaturing Cities through Nature Based Solutions. Interventions in Valladolid. Horizon 2020. Available online: https://www.urbangreenup.eu/kdocs/2049925/ugu-valladolid-infopack_digital.pdf (accessed on 22 March 2023).
48. New Strategy for Renaturing Cities through Nature Based Solutions. Interventions in Liverpool. Horizon 2020. Available online: https://www.urbangreenup.eu/kdocs/2049805/ugu-liverpool-infopack_digital.pdf (accessed on 22 March 2023).
49. New Strategy for Renaturing Cities through Nature Based Solutions. Interventions in Izmir. Horizon 2020. Available online: https://www.urbangreenup.eu/kdocs/2049804/ugu-izmir-infopack_digital.pdf (accessed on 22 March 2023).
50. *ISO 37120:2014*; Sustainable Development of Communities—Indicators for City Services and Quality of Life. Polish Counterpart PN-ISO 37120. ISO: Geneva, Switzerland, 2014.