



Article Development of a Management Framework for Applying Green Roof Policy in Urban China: A Preliminary Study

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Abstract: Increased consumption of energy and resources by urbanization has caused increasing concerns regarding the sustainability of building practices around the world. Green roofs (GRs) are attracting increasing attention as an important means to overcome environmental challenges related to urbanization. Although GRs have been widely applied in some areas throughout the world, their development is lagging in China. This paper reviews international GR policies with the aim to develop a framework for applying GR policies in suitable areas of China. After summarizing the typical environmental characteristics and GR policies in China, policies that can expedite GR implementation were recommended. By analyzing the national conditions (climate conditions, economic development, urban construction and policy circumstances), 23 GR policies were identified and divided into three categories (i.e., mandatory policies, incentive policies and assistance policies). Based on the attributes, the policies were developed into a framework that combined the three development stages of GRs (i.e., the pilot exploration stage, the progressive promotion stage and the overall application stage). These findings will help to formulate a GR strategy in China and provide important insights for other countries.

Keywords: green roofs; policy; sustainable development; urban; China

1. Introduction

In 1950, urbanization averaged 30% of the world and a period of rapid urbanization that proceeded for the following 60 years was entered [1]. Various environmental problems are associated with the urbanization, such as severe heat, stormwater runoff, and reduced biodiversity [2,3]. Further, these problems lead to increased health problems and consumption of resources and energy [4–6]. According to the data from the United Nations Environment Programme, buildings account for 40% of the total energy consumption [7], and China is a typical country where the construction industry is the main energy consumption sector. Its technological development improves the comfort of occupants while also causing a sharp increase in energy consumption [8]. China's energy consumption ranks first in the world, with an average primary energy efficiency of 30% [9]. Therefore, it is necessary to ameliorate problems related to urbanization through sustainable building practices [4,10].

Green roofs (GRs) provide an environment-friendly solution [11,12]. The numerous benefits of GRs have been widely recorded in the international knowledge, including the mitigation of urban heat islands [13], the reduction of urban waterlogging [14,15], saving energy [16], enhancement in

air quality [17], increased biodiversity [18], and reduced noise pollution [19,20]. Although there is short-term cost inefficiency of GRs in comparison to traditional methods, their implementation on an urban scale can greatly reduce costs, and the potential economic benefits are notable [12,21,22]. In general, the life cycle value and financial returns of GRs have been robust in various geographical locations and climatic conditions [23], directly resulting in an increasing number of cities establishing mandatory requirements [24].

The success of GR implementation hinges on many factors [25,26]. Dhakal and Chevalier [25], based on a critical literature review conducted in 10 US cities concluded that while the options of green infrastructure (e.g., green roofs, rain barrels) vary from place to place, adopting green infrastructure faces similar obstacles in different countries and regions, and most obstacles stem from higher cost, cognitive limitations (lack of awareness) and socio-institutional arrangements. Chen et al. [27] identified the maintenance, design and construction cost, poor arrangement of GR adoption, and lack of incentives as the root factors impeding GR implementation in urban China. For these factors, policy could improve collective awareness and participation in GR implementation [4,24]. In terms of costs, financial policies such as grants, rebates, and subsidies can leverage investment in GRs [24]. The assessment of international GR policies shows that the government has significantly contributed to GR development by providing financial support and appropriate supervision [4]. According to the above analysis, policy is the key factor affecting GR implementation since it provides guidance on shared outcomes for public behavior [25] and is essential to promote the application of a new technology. In addition, it is reasonable to conduct public intervention by GR policies due to the public benefits provided by GRs [26,27]. Brudermann and Sangkakool [28] revealed that without policy interventions, GRs seemed unlikely to move from the ecological niche to the regime level in the near future.

The promotion of urban GRs has always been a discussion topic in academia. The mainstream literature focuses on GR technology, benefits, design and so on [29,30]. In comparison, studies on GR policies were less numerous. In this topic, researches are mostly conducted on the types and characteristics of international GR policies (mainly developed countries). Carter and Fowler [26] evaluated international and North American GR policies which were divided into regulation, financial incentives, and funding of demonstration or research projects. Based on the discussion of policy advantages and disadvantages, it was recommended that policy instruments were proposed to be multi-faceted and spatially focused. Liberalesso et al. [31] identified and analyzed the policies used to promote the uptake of GRs and green walls in 19 countries worldwide. The findings show that policies are mainly concentrated in Europe and North America, and financial subsidies and obligations by law are the most common ways to promote GRs and green walls. Another core theme is the effectiveness exploration of GR policies. Irga et al. [4] researched the distribution of GR projects in urban Australia, and the influence of local policies designed to promote GR increase, indicating that the policy tools of local government were closely related to the GR implementation, and further policy implementation could increase the frequency of GR projects. In another study, Tassicker et al. [32] critically analyzed the state-of-practice in Australian GR industry through literature review and semi-structured interviews, indicating that government should adapt GR policies to better encourage GR adoption. Additionally, cities with a relatively high GR proportion (such as Stuttgart and other cities in Germany), clearly demonstrate the effectiveness of policy interventions, especially when the city is growing or renewed, where many new buildings are being built [28].

Across the globe, GR policies of major developed countries such as Europe and America have a history of more than 30 years. In contrast, the practice of GRs is relatively lagging behind in China. The Chinese government has introduced some GR policies, mainly in first-tier large cities. Whilst the efforts are designed to support GR adoption, there has been a lack of comprehensive assessments of these policies. Xiao et al. [9] studied the selection of planting materials, plant growth medium and ecological benefits of the GRs in China, and only briefly analyzed the GR policies at that time (before 2014). While, in recent years, the GR policies have been further developed and updated.

Nevertheless, so far, a framework for GR development is yet to be set up. The experience accumulated in GR implementation around the world can provide a reference, but the particularity of China's national conditions may lead to a decrease in the applicability of certain experience in China [24]. Various policies need to be adjusted by referencing international experience and local conditions. In summary, the limited researches have studied the GR policies in developed urban areas but ignored developing countries, whose GR implementation is still in its infancy. The literature review and our own views emphasized the need to carry out local research on the development of GR policy framework for the particularity of national conditions in developing countries. The current research represents the first study to establish, systematically, a framework for China's conditions to promote the local GR industry, and will help in providing reference for other developing countries to formulate targeted policies. The specific objectives of the paper are as follows:

- 1. Overview and critically analyze the international GR policies to recognize their particularities and features.
- 2. Summarize national local conditions affecting policy-making and investigate GR policies in China.
- 3. Identify suitable GR policies and establish a framework of GR policies for China's local conditions.

2. Methodology

This study mainly included two parts. In the first part, we summarized the international GR policies through an analysis of the existing literature. Information was collected via a web-based search of global documents, and the criterion for selecting research cities was the availability of GR policy information. We analyzed the GR policies of 4 continents, including Europe (e.g., Austria, Belgium, Czech Republic, Denmark, France, Germany, Italy, Netherlands, Switzerland), North America (e.g., Canada, Mexico, the United States), South America (e.g., Argentina, Brazil), Asia (e.g., Japan, Singapore). The widely analyzed materials included journal papers, books, case studies, academic conferences, etc.; and the recent reports from the European Federation of Green Roof and Green Wall Associations (EFB) based in Vienna, Austria and North American Green Roofs for Healthy Cities (GRHC) based in Toronto, Canada were also reviewed. Among them, "Green Roof and Wall Policy in North America 2019" [33] comprehensively analyzes the policies, types, obstacles, implementation, benefits, case studies, and lessons learned on green roofs and green walls in North America; and, "Living Roofs and Walls from Policy to Practice—10 Years of Urban Greening in London and Beyond 2019" [34] conducts a review and comparison of the implementation data and policies of the green roofs and green walls in London and cities around the world.

In the second part, based on the summary of the local conditions in China (climate conditions, economic development, urban construction and policy circumstances), policy recommendations were proposed to expedite GR implementation. To this end, a detailed investigation was conducted on the current status of GR development in China. The investigated documents supporting the implementation of GRs included ordinances and other legal documents; codes, specifications, standards, rules, guidelines, technical regulations and other regulatory documents; plans, manuals, opinions, planning of GRs and other guiding documents. The methodology used was a web-based search to mainly identify two issues: the incentive measures currently adopted by different levels of government agencies (state, province, and city), and the details of incentive measures. On this basis, taking Beijing and Shanghai as the key investigation objects, GRs were widely implemented in these cities. Finally, according to the research results (applicability of international GR policies and local conditions in China), a GR policy framework for China was developed (see Figure 1).



Figure 1. The formulation of the green roof policy framework of China.

3. International Green Roof Policies

From a global perspective, GR policies are mainly concentrated in Europe and North America, and obligations by law is the only GR promotion policy available on all four continents. In comparison, European cities have more progressive policies to encourage GRs, with the most successful way providing financial incentives or requiring mandatory implementation of GRs [4] (see Table 1). According to the statistics of the global urban GR area in 2015 [34] (see Figure 2), most cities with a higher density of GRs are in Austria, Germany and Switzerland, which first adopted policies and incentives for GRs. Among them, Basel has the largest area of GRs per capita (5.71 m²), followed by Stuttgart and Linz. From a global perspective, the earliest GR industry appeared in Germany. This makes Germany, which has had GR policies for more than 40 years, the most advanced country for GRs in the world. Over the past 15 years, due to government and individual concerns about environmental sustainability, GR installation has increased significantly. At present, countries such as the US, Canada, Australia, Singapore and Japan are vigorously advocating GRs [27].



Figure 2. Ranking of global GR area and density in 2015.

City	Policy	Details	Effect
Basel, Switzerland	Building and Construction Law (BCL) of 1996–1997, 2002, and 2005–2006	BCL of 2002 requires that all flat roofs of new and renovated buildings must be greened. BCL of 1996–1967 and 2005–2006 subsidize about \$20.5/m ² for GRs.	By 2015, there were over 100 ha of GRs and 5.71 m ² of GRs per capita (the largest area of GRs per capita of the world).
Stuttgart, Germany	City of Stuttgart regulations of 1986, Climate Atlas of 2008, German Building Code (GBC), FLL Green Roof Guidelines of 2008	City of Stuttgart provided subsidies for GRs; Climate Atlas provides planning recommendations based on climate assessment; GBC mandates GRs on all new flat-roofed buildings; Green Roof Guidelines provides comprehensive technical guide.	By 2015, there were 30 ha of GRs and 3.38 m ² of GRs per capita.
Linz, Austria	City building codes of 1985, Green space program	City building codes included an obligation for new buildings to have GRs, reimbursing up to 5% (reduced from 30% in 2005) of the cost of installing a green roof as an incentive, which finally ended in 2016.	By 2015, Linz had 50 ha of GRs and 2.57 m ² of GRs per capita.
London, UK	London Plan of 2008, Living Roofs and Walls Guidance Note of 2008, Green Roofs and Development Site Environs Policy and Urban Greening Policy within London's Response to Climate Change of 2015, Biodiversity Action Plan of 2010–2015, Green Roof Map of 2013	GR policy was included in the London Plan of 2008. "The Mayor will, and boroughs should, expect major developments to incorporate living roofs and walls where feasible and reflect this principle in Local Development Framework policies", and a technical report to provide comprehensive information on GR benefits, costs, maintenance, and case studies was published. Climate Change of 2015 encouraged sustainable building design including GRs.	By 2010, London had 71.5 ha of GRs. By 2017, it had over 150 ha of GRs and 0.17 m ² of GRs per capita, and 42% of the total UK GR market was in London.
Washington, USA	Clean Water Act of 1987, RiverSmart Programs of 2007, Stormwater Retention Credit Training Program of 2013, Washington DC Municipal Management Regulations (DCMR) of 2013, Green Roof Rebate Program of 2016, Green Area Ratio of 2017	Clean Water Act requires communities managed by integrated stormwater network systems to implement best management practices. DCMR requires stormwater management measures for specific projects. All new buildings with a Certificate of Occupancy must meet the Green Area Ratio based on zoning district. RiverSmart Programs provide \$5/ft ² tax-free funding for GRs.	By 2015, Washington had 0.37 m ² of GRs per capita, In recent years, Washington has held the top spot for GR installations in North America.
Sydney, Australia	Green Roofs and Walls Policy of 2014, Environmental Performance Grants supported by Sustainable Sydney of 2030	Policy provides comprehensive information of GR benefits, obstacles and design considerations and a resource manual for GRs. Grants provides subsidies for GRs.	Since 2014, Sydney's green roof and wall coverage increased by 23%.
Melbourne, Australia	Growing Green Guide of 2014, Green Our City Strategic Action Plan of 2017-2021	Guide provides information on GR benefits, installation and considerations. Plan helps develop industry standards, and develops partnerships with the private sector to co-fund greening through the Urban Forest Fund. One of the targets is to double the area of GRs and vertical greening by 2021.	By 2015, Melbourne had 54,000 m ² of GRs and 0.36 m ² of GRs per capita.

Table 1. International GR (green roof) policies, modified from Irga et al. [4].

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City	Policy	Details	Effect
Melbourne, Australia	Growing Green Guide of 2014, Green Our City Strategic Action Plan of 2017-2021	Guide provides information on GR benefits, installation and considerations. Plan helps develop industry standards, and develops partnerships with the private sector to co-fund greening through the Urban Forest Fund. One of the targets is to double the area of GRs and vertical greening by 2021.	By 2015, Melbourne had 54,000 m ² of GRs and 0.36 m ² of GRs per capita.
Portland, USA	Ecoroof Requirement Private Property Retrofit Program of 2018, Green Building Policy of 2001, Clean River Rewards of 2005, Stormwater Management Manual of 1999	New buildings with a building area of 20,000 ft ² or more must have an eco-roof that covers 100% of the building area (with exceptions), the eco-roof floor area ratio bonus rewards 3 ft ² /ft ² of green roof and stormwater reduction discount are provided.	By 2015, Portland had 15.8 ha of GRs and 0.27 m ² of GRs per capita.
Chicago, USA	Sustainable Development Policy of 2017, Green Roof Incentives of 2015, Green Permit Program of 2014, Adding Green to Urban Design Plan of 2008, Sustainable Development Policy of 2007, Green Roof Improvement Fund of 2006, Green Roof Grant Program of 2005	Sustainable Development Policy requires that development projects earn a number of points by implementing select sustainable strategies (including GRs), and all new developments are required to reach 100 points. GR projects can receive reduced permit fees, priority development review and financial incentives under different policies, such as providing 50% of the cost or \$100,000 for GRs construction covering 50% or more of the roof space.	By 2015, Chicago had 50.8 ha of GRs and 0.19 m ² of GRs per capita.
Tokyo, Japan	Tokyo Green Plan of 2012, Tokyo of 2020, Green Building Program of 2002, Tokyo Metropolitan Condominium Environmental Performance Labelling System, 10 Year Project for Green Tokyo of 2006, National Building Law of 2005	The Tokyo Green Plan of 2012 provides tax incentives and mandates 20% of rooftop of private buildings more than 1000 m^2 and public buildings more than 250 m^2 must be greened. National Building Law requires new apartments or office buildings in urban areas to cover 20% of GRs.	By 2015, Tokyo had 134.5 ha of GRs and 0.1 m ² of GRs per capita.
Toronto, Canada	Green Roof Bylaw of 2009, Eco-Roof Incentive Program of 2009, Guidelines for Biodiverse Green Roofs of 2013	New commercial, institutional and residential developments with a minimum gross floor area of 2000 m ² are required to have GRs. Eligible GRs receive CAD \$75/m ² up to \$100,000 through an incentive program. Comprehensive guidelines on GR benefits, design, and maintenance given.	500,000 m ² of GRs were developed from 2009 to 2018.
Singapore, Republic of Singapore	Skyrise Greenery Incentive Scheme of 2009 (SGIS), SGIS 2.0 of 2015, Landscaping for Urban Spaces and High-Rises of 2009 (LUSH), LUSH 2.0 of 2014	SGIS supports 50% of the GR installation costs; LUSH provides incentives and development exemptions for GRs.	By 2016, Singapore had 72 ha of GRs and green walls, and 0.19 m ² of GRs per capita.
Copenhagen, Denmark	Copenhagen Climate Plan of 2025, Sustainability in Constructions and Civil Works (SCCW), Green Roofs Copenhagen Guidance Note of 2012	SCCW requiring GRs of municipal buildings. Since 2010, the city has created GR policies in local plans require roofs with a pitch of less than 30° to be greened, and there are also incentives available for the refurbishments of older roofs.	By 2015, Copenhagen had 40,000 m ² of GRs 0.07 m ² of GRs per capita.

3.1. Europe

Germany began to promote GR construction as early as the 1970s [19,28]. In 1975, the formation of the Forschungsgesellschaft Landschaftsentwicklung, Landschaftsbau (FLL) based in Bonn, Germany solidified the core of the national GR interests [26]; and in 1982, legislation made implementing GRs mandatory. Governments at all levels, from federal to state and city, have introduced GR policies across Germany, where the Federal Building Code mandates GRs on new flat-roofed buildings through land use planning [4]. GR policies were introduced in German cities in the late 1980s and many include mandatory requirements. Among them, the development of GRs in Stuttgart is the epitome of the development in Germany. Stuttgart became the first city in Germany to integrate GRs into local development plans in 1985 [4], which mandated GRs in all new developments. In addition, Stuttgart has a funding program for GRs which pays up to 50% of the cost up to a maximum of €10,000 [34].

Switzerland is another leader in GR adoption, with Basel deemed to be the pioneer in Switzerland [4]. Initiatives to promote GRs in Basel were initially driven by energy-saving plans, followed by biodiversity conservation [34]. Under the Building and Construction Law in 1996, Basel mandates GRs on flat roofs of all new and renovated developments, and subsidies were provided to support this initiative [4]. Linz, Austria, was one of the first cities in the world to implement GR policies. In 1989, the municipal government provided subsidies to encourage GRs and City Building Codes required GRs on new buildings [34]. Malmö has always been at the forefront of GR development in Scandinavia. In the early 21st century, the first GRs were implemented in the Augustenborg of Malmö. It was also the first city in the region to use landscape planning tools to support greening. Although no French city has appeared in the global table, France has been the only country in the world to enact national law on GRs since 2016. The environmental law requires that all new commercial building roofs must be covered by green plants or solar panels [34].

3.2. North America

Although the GRs in North America started later than in Europe, they have developed rapidly in recent years. GRHC, the largest GR advocacy organization in North America, has played a major part in promoting the development of GRs. In recent years, GRHC has been directly involved in policy development in multiple cities, and developed a GR calculator (GreenSave Calculator) to address the issue of cost [33]. Its Green Roof Professional (GRP) program focuses on the best practices of GRs. Additionally, GRHC and the Green Infrastructure Foundation have been working on developing a comprehensive performance evaluation system for GRs and green walls called "The Living Architecture Performance Tool (LAPT)" [33]. In addition, federal and local governments in North America have formed a range of GR policies. Stormwater management regulations in the Federal Water Pollution Control Act and Clean Water Act are directly applicable to GRs, and many federal agencies also indirectly encourage GRs by green building requirements [26]. At the municipal level, over the past 15 years, more than 31 North American jurisdictions have targeted GR requirements or put incentives in place to achieve multiple policy objectives, such as green building and stormwater management (see Table 2). Among them, Washington, DC, holds the top spot for GR area per capita, followed by Chicago, Toronto, New York, and Seattle [33]. Similar to Europe, municipalities with supportive GR policies continue to dominate annual GR installations.

Some GR policies utilize control approach by performance-based or technological standards [26]. In 2009, Toronto, Canada, became the first local government to mandate GRs in North America [34]. The Green Roof Bylaw requires GRs on all new residential, commercial and institutional developments with a floor area greater than 2000 m² [4]. In 2016, Toronto became the city with the largest GR area in North America. In Washington, DC, in addition to meeting the provisions of the Federal Clean Water Act to control overflow, all new buildings that require a Certificate of Occupancy must meet the appropriate Green Area Ratio. In 2017, the first mandatory GR policy in the USA, the San Francisco Better Roof Ordinance, came into effect. The ordinance stipulates that in most new construction projects, 15% to 30% of the roof space must use solar energy, GRs, or both [34].

Some cities make use of a market-based approach by grants, rebates, subsidies and nonfinancial incentives [26]. Chicago was one of the early cities to provide financial incentives for GRs, including, without limitation, the Green Permit Benefit Tier Program of 2015, the Green Roof Incentives of 2015 and the Sustainable Development Policy of 2017 [4,33]. The RiverSmart Rooftops Program in Washington, DC, provides subsidies for the implementation of GRs. Portland and Seattle both utilize a Floor Area Ratio bonus to encourage GRs in all new projects [4].

Location	Regulation	Tax Credit	Funding	Stormwater Fee Credit	Density or Floor Area Ratio Bonus	Green Factor
Washington, DC	Δ		Δ	Δ		
Chicago, IL	Δ				Δ	
Toronto, ON	Δ		Δ			
New York, NY	Δ	Δ	Δ			
Seattle, WA	Δ		Δ	Δ	Δ	Δ
Adams County, CO				Δ		
Austin, TX					Δ	
Baltimore, MD				Δ		
Denver, CO	Δ					
Devens Enterprise Zone, MA	Δ			Δ		
Fife, WA	Δ					Δ
Fort Wayne, IN			Δ			
Guelph, ON			Δ	Δ		
Hoboken, NJ					Δ	
Kitchener, ON				Δ		
Marion County, IN				Δ		
Milwaukee, WI			Δ			
Minneapolis, MN				Δ		
Montgomery County, MD			Δ			
Nashville, TN			Δ	Δ		
Palo Alto, CA			Δ			
Philadelphia, PA		Δ	Δ	Δ	Δ	
Portland, ME				Δ		
Portland, OR	Δ					
Prince George County, MD			Δ			
Saint Laurent, Montreal, QC	Δ					
San Francisco, CA	Δ					
Syracuse, NY			Δ			

Table 2. GR policies in North American jurisdictions.

3.3. Asia

In Asia, different from the drivers of European and American environmental benefits, the urban high-density development leading to the lack of green space has accelerated the GR implementation. Although Singapore is internationally recognized for creating green spaces on the roof, the density of GRs is relatively small compared with European and American cities. Its Skyrise Greenery Program encourages GRs, and the Skyrise Greenery Incentive Scheme (SGIS) released in 2009 supports 50% of the GR installation costs. Landscaping for Urban Spaces and High-Rises (LUSH) provides development exemptions for GRs [4]. The Japanese government began to provide low-interest loans to owners of roof gardens in 1999. The National Building Law of 2005 requires new apartments or office buildings in urban areas to cover 20% of GRs. The Tokyo Green Plan of 2012 provides tax incentives, and mandates 20% of the rooftop of private buildings more than 1000 m² and public buildings more than 250 m² must be greened [4,26].

3.4. South America

The GR policies in South American mainly include mandatory requirements, tax reductions and construction permits. Guarulhos in Brazil mandates GRs for new buildings with more than three floors. Recife in Brazil and Cordoba in Argentina require building with a floor area more than 400 m² to

include GRs approved by the municipality. In Goiânia and Guarulhos, landowners who adopt the Best Management Practices are entitled to a maximum property tax reduction of 20% for a period of five years, with GRs accounting for 3% of the total discount. Similarly, in Santos, property tax reduction ranges from 1.5% to 3% based on GR area for a maximum period of three years. Rio de Janeiro has established a "Qualiverde" certification program to encourage sustainable practices, and certified projects have priority in the construction permit process [31].

4. Applicable Green Roof Policies in China

4.1. Typical Situations of China

It is essential to investigate typical situations of China to lay the foundation for the formulation of GR policy framework due to the Chinese vast territory with different climate zones, economic development, urban construction and policy environments [9].

4.1.1. Climate Conditions

The suitability of GRs depends largely on climatic conditions which directly affect the living conditions of green roof vegetation [35]. The climates in the north and south of China are quite different. To fully adapt a building to different climatic conditions in China, China's national standards "Building Climate Zoning Standard" GB50178 and "Uniform Standards for Civil Building Design" GB50352-2019 divide China into seven main climate zones, and put forward different requirements for the architectural design of each climate zone (see Figure 3). GRs, as an additional facility of the building, should meet the requirements of the standards. Therefore, according to the characteristics of different climate zones, the GR promotion in China should give priority to zones III, IV, and V for heat protection, followed by zones II for cold resistance and wind protection.



Zone I -severe cold region Zone II-cold region Zone III-region of hot summer and cold winter Zone IV-region of hot summer and warm winter Zone V-temperate region Zone VI-severe cold region and cold region Zone VII-severe cold region and cold region

Figure 3. Building climate zones of China.

4.1.2. Economic Development

China is the largest developing country which often sacrifices the environment for economic development [27,36,37]. Since the reform and opening-up, due to its extensive economic development, the environmental problems of developed countries have become prominent in China and have been compressed and compounded. In 2015, the construction of the ecological civilization was included in the "13th Five-Year Plan" for the first time, raising environmental protection to a national strategic level, and providing good opportunities for GR development. In addition, there is a large gap in the regional economic development levels in China. Priority should be given to economically developed areas such as national central cities for policy-making that concentrate on China's main spatial, population, and resource advantages.

4.1.3. Urban Construction

China is one of the countries with the most concentrated distribution of high-density cities [38]. With the rapid development of urbanization, the building density is increasing and the urban green space is decreasing. Despite some measures which have been undertaken by leading cities in China, the practice of GRs is still lagging behind. There is still a considerable gap between China and Western countries and other Asian counterparts such as Singapore and Japan [39]. According to global GR area statistics in 2015 [34], the GR area per capita in developed cities in Europe and America is more than 1 m² while those in Shenzhen, Beijing, and Shanghai with relatively large areas of GRs in China are only 0.21 m², 0.1 m², and 0.09 m², respectively. Consequently, there is a great prospect for GR installation on existing buildings to deal with environmental problems in suitable areas of China.

4.1.4. Policy Circumstances

The GR development of China has obvious Chinese characteristics, which are manifested in the different basic drivers caused by different policy circumstances. In European and American countries, due to strict environmental protection policies and various types of environmental taxes, GRs are regarded as an environmentally sensitive and sustainable building technology, and the environmental benefits are the main driver for GR deployment. In China, the beautification of a city's fifth facade is the impetus for GRs, whose positioning in the urban green infrastructure has not reached an important height due to the lower appreciation of their potential environmental benefits. In terms of environmental protection, at present, only Beijing has proposed a flood relief policy. Therefore, in the context of ecological civilization construction, China should improve the positioning of GRs and learn from the environmental protection policies of European and American countries to encourage ecological and environmental investments in GRs.

4.2. Policy Instruments of Green Roofs in China

4.2.1. Policy at the State Level

The GR policy at the state level mainly determines the general direction and goals. The State Council's Notice on Strengthening Urban Greening Construction (Guo Fa, (2001) No. 20) emphasized to fully utilize roofs for greening. The State issued the "Planted Roof Engineering Regulation" (JGJ155-2007) and "Planted Roof Waterproof Membrane with Root-puncture-resistance" (JC/T1075-2008) to provide technology support [9]. In 2010, the "Urban Garden Greening Evaluation Standards" (GB50563-2010) incorporated an encouragement policy, technical measures and the implementation plan of vertical greening as the evaluation standards. The new version of the "National Garden City Series Standards" released in 2016 requires national garden cities to make policies for the promotion of vertical greening. In the new version of the "Green Building Evaluation Standard" (GB/T50378-2019), GRs are included in the evaluation index as a measure to alleviate urban heat islands.

4.2.2. Policy at the Provincial and City Levels

Chinese governments at the provincial and city levels have also implemented a series of GR policies in recent years (see Figure 4), mainly including legislation such as urban greening ordinances; regulations such as technical norms, standards and methods; guiding policies such as planning, proposals and plans; and incentive policies such as financial subsidies. The provinces of Hainan, Shanxi, and Zhejiang, and cities of Shanghai, Shenzhen, Hangzhou, and Chongqing have promoted GRs through urban greening ordinances, but the application scope is mainly for new, rebuilt and expanded municipal public facilities or public buildings; and except for Shanghai and Shenzhen that have detailed content requirements for GR construction, supervision, and responsibilities, the ordinances of other cities are only weak mandatory descriptions such as "encourage development". In addition, technical regulations need to be summarized and improved in further practice. The incentive policies



are mainly financial subsidies and bonuses for green space rates, but fewer provinces and cities adopt direct financial subsidy policies due to the government's financial burdens.

Figure 4. Distribution of cities with GR policies in China.

The cities with larger GR areas in China are mainly developed cities, such as Beijing, Shanghai, Chengdu and Shenzhen. Beijing is one of the earliest cities to construct GRs in China and is also a pioneer in the promotion of GRs in northern cities. In 1983, the roof garden of the Beijing Great Wall Hotel became the first large-scale GR project in northern China. In 2004, "Beijing Urban Environment Construction Planning" required that 30% of the rooftops of high-rise buildings and 60% of the rooftops of low-rise buildings to be greened. In 2005, "Beijing Green Roof Code (DB11/T281-2005)" became an important basis for GR construction and management in Beijing and even northern cities. Taking the 2008 Olympic Games as an opportunity, Beijing promoted GRs in a big way, made overall arrangements for vertical greening work including GRs in 2011, and issued the "Proposal of Promoting Construction of Urban Space Vertical Greening" (Jingzhengfa, (2011) No. 29). It stipulates that when the auxiliary greening area of new construction or reconstruction projects fails to meet planning requirements, it is mandatory that GRs must be built for more than 50% of the building rooftop area, and 20% of the GR area can be green area. When the auxiliary greening area meets the requirements, the flood control fee reduction policy will be implemented according to the GR area.

Shanghai, with the most comprehensive GR policies, is the first city in China to implement a mandatory GR policy on public buildings in the form of legislation. The "Shanghai Greening Ordinance" issued in 2007 stated that GRs shall be installed for new public service facilities suitable for roof greening. The 2010 Shanghai World Expo is a major turning point in the development of GRs in Shanghai. "The Implementation Proposal of Promoting the Development of Vertical Greening" issued in 2014 proposed GRs as a new growth point of urban greening and released the "Special Planning for Shanghai Vertical Greening" in 2016. From 2011 to 2016, a total of 1.64 million m² of vertical greening were built. In terms of technical support, Shanghai has successively launched a series of normative technical documents, including the "Shanghai Green Roofs Technical Specifications" and "Vertical Greening Technical Specifications". Regarding incentive policies, the 2014 "Implementation Proposal of Conversion of New Green Roofs to Supporting Green Space" specifies the conversion method of the GRs and green spaces of new buildings. In addition, the 2016 "Guidelines of Support Funds for Vertical Greening Demonstration Project in Shanghai" provides a subsidy of \$7–28/m² for GRs.

4.2.3. Policy Summary

Although the government has issued a series of GR policies, the implementation of GRs in China is still at its initial stage. Compared with the rapid progress of GR technology, the GR policies lack a top-level system design, resulting in a weak policy foundation and weak effectiveness, which are important constraints.

- The policy system needs to be established. Due to the differences in natural resource cognition caused by the long-term division of administrative management in the past, the existing public policies in various cities usually lack systematization and the height and perspective of cross-disciplinary collaboration. They are insufficiently linked to related policies such as ecological environmental and water resource protection, resulting in a single type of policy with a small application scope and poor sustainability. With the institutional reform of the State Council and the establishment of the Ministry of Natural Resources, land space governance emphasizes breaking the constraints of the administrative function division. It is necessary to build a plan-oriented GR policy system that covers interdisciplinary and multisector collaboration to improve the top-level design of the policy system.
- Policy details need to be improved. Even in advanced GR cities, the policies for promoting GRs in China are outdated [9,27]; e.g., GR policies mostly use words such as "appropriate", "encouraging" and "advocating", which are inadequate compared with European and American countries. Compared with foreign GRs, which can be effectively and largely included in green areas, the conversion rate of GRs in China is lower, due to it having requirements, such as, on the building height, function, and plant types. In addition, most of the financial incentive policies issued by cities in China are fixed-point targeted subsidies (such as public buildings).

4.3. Recommended Green Roof Policies for China

Effective policies should be suitable for local conditions [24,40]. In order to better understand the applicability of international GR policies, a preliminary study was conducted to select the policies applicable to China based on climate conditions, economic development, urban construction and policy circumstances. GR policies were divided into three categories, namely, mandatory policies, incentive policies and assistance policies, and further divided into seven subcategories. According to the categories of GR policies and the national conditions of China, 23 GR policies are recommended (see Table 3).

Categories		Policies	N.
Mandatory	Legislative policies (LP)	Add the requirement of hydrological maintenance in existing legislation (e.g., the Urban and Rural Planning Law of the People's Republic of China)	LP1
policies		Formulate orunnance for GKS	LI Z
	Regulatory policies (RP)	Formulate regulations, codes and standards for GRs Use the planning tool for the green space factor innovatively	RP1 RP2

Table 3. Recommended green roof polici	ies for China
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Categories		Policies	N.
	Guiding policies (GP)	Develop a GR plan Compile special planning for GRs	GP1 GP2
		Develop technical guidelines on GR design, construction, and maintenance	GP3
		Develop GR cost-benefit calculation tools	GP4
Incentive policies		Flexible administrative management process (project development permission priority, etc.)	GP5
	Financial policies (FP)	Establish research funds for GRs	FP1
		Launch a financing scheme for GRs	FP2
		Provide low-interest loans for GRs	FP3
		Tax reductions	FP4
		Bonus based on density, floor area or green space ratio	FP5
	Evaluative policies (EP)	Incorporate GR elements in existing or newly established evaluation systems related to ecological sustainable development (e.g., low-carbon cities)	EP1
		Develop a comprehensive performance rating system for GRs	EP2
		Establish GR labeling system	EP3
Assistance policies	Organization policies (OP)	Establish the association, organization, and institution for GRs	OP1
		Provide professional training	OP2
		Establish professional GR system construction team	OP3
	Information policies (IP)	Promote public awareness of GRs (e.g., publicity of large events)	IP1
		Provide knowledge sharing platforms (e.g., websites)	IP2
		Encourage GR innovation (e.g., competitions)	IP3

Table 3. Cont.

4.3.1. Mandatory Policies

Mandatory policies provide the highest level of insurance, which are particularly applicable to new urban development areas, and have generally been considered to be the most powerful policies [41]. Policy objectives are usually diverse, such as reducing the impervious roof area, improving water quality, and alleviating urban heat islands. Mandatory policies can establish markets and provide predictable demand to significantly reduce construction and maintenance costs of GRs. Moreover, without mandatory policies for GRs, it is hard to implement incentive policies [24]. Nevertheless, mandatory policies may be politically unpopular and face a number of obstacles in the process of implementation, such as the limited application scope [26,42], and usually, public buildings whose property owners are the government, with few interest disputes. Similar to the above, China currently only has mandatory policies for newly built public buildings. Specifically, "Shenzhen Greening Ordinance" stipulates that "newly built public buildings and municipal facilities should implement GRs in accordance with relevant standards and technical specifications". In addition, The Green Roof Ordinance passed by Denver in 2017 mandated green roofs on both new and existing buildings. The requirements for GRs on all existing buildings led to well-organized and funded opposition to the initiative, and it was ultimately amended to mandate that buildings have a cool roof and one of the compliance options (including GRs) [33]. Considering this, mandatory policies that offer a variety of compliance options make it easy to implement policies, and are recommended in the medium- and long-term of GR implementation, while adopting other supporting policies to deal with their obstacles in China [24]. Promoting GRs through the creation of legislation is an important form of mandatory policy. At present, China has no state laws to promote GRs. It is recommended that the Urban and Rural Planning Law adds requirements for the hydrological maintenance and includes provisions for GRs in the implementation rules. Meanwhile, local governments are encouraged to legislate to clarify GR responsibilities according to local conditions and to effectively incorporate GRs into the scope of the legal obligations during the construction phase.

It is another mandatory policy for the government to issue GR tasks in the form of administrative orders through technological and performance-based standards and to incorporate GRs in the mandatory content of development planning through planning tools. Technological standards mandate the use of GRs over all specific types of buildings [26], generally based on the building's function, height, floor space and roof form. Performance-based standards may achieve environmental controls in parts of the city through the use of GR technology, such as stormwater management, rooftop reflectivity, or urban green space [26]. Using performance-based standards instead of specifying components makes the market flexible in best meeting performance requirements while allowing for the evolution and innovation of technical approaches. The green space factor planning tool restricts development and construction by leaving a certain percentage of area as green space and specifying the lower limit of an index, such as the Biotope Area Factor of Berlin, the Green Space Factor in Malmo, and the Green Factor in Seattle, which have successfully promoted the construction of urban green infrastructure.

4.3.2. Incentive Policies

Guiding policies, such as planning and technical guidelines, provide direction guidance for the future work of developers and market trends [43]. Consequently, the guiding policies will play a greater role in the early stage [21,24]. At present, only Shanghai, Shenzhen and Xiamen in China have compiled special planning for urban GRs. In addition, understanding the added benefits and cost of a new technology is important for short-term and long-term effectiveness [33]. Developing GR cost-benefit calculation tools for financial analysis, combined with local conditions and actual costs according to expertise and industry, can address concerns about initial costs of GR installation and maintenance. Besides, financial analysis should be applicable to various building types (for example, residential and commercial buildings face different cost and benefit scenarios).

Financial policies are deemed to be supplementary options of mandatory policies [24,44], and mainly include direct economic incentives such as funding, subsidies, and rewards (instead of subsidies), as well as indirect economic incentives such as tax reductions, low-interest loans and bonuses based on floor area or the green space ratio. According to previous studies, high costs (construction costs, maintenance costs) are the biggest obstacle to GR implementation, and China is no exception [12,27]. Compared to guiding and mandatory policies, financial policies are not only more effective in the short term [24,41] but also are the most effective way to form a long-term mechanism for solving environmental problems so far. Therefore, it is suggested to implement financial policies throughout the roof greening process. Direct financial subsidies can compensate owners for the initial construction costs [26,42,45]. However, these policies raise the fiscal burdens for governments and are more suitable for economically developed cities. Indirect financial policies do not require substantial financial investments, while it is hard to guarantee GR implementation [26]. Among them, bonuses based on density, floor area or the green space ratio are the most widely used, economically feasible, and effective incentive policies in nonmonetary policies; however, in China, only Beijing, Shanghai, and Hangzhou have green space ratio conversion standards. In addition, an environmental protection tax is an important means of economic control, and policies establishing environmental protection taxes are recommended in response to environmental problems such as stormwater and high temperatures in China. Among the international trends, there is growing interest in policy connected with the financing of green infrastructure, such as the European Investment Bank's Natural Capital Financing Facility [34] and municipal green bonds [25]. Innovative long-run funding mechanisms should be established in China.

The objective of evaluative policies (e.g., labels and ratings) is to ensure that GR projects can achieve quantifiable and replicable performance benefits and increase the public confidence in the use of GRs. In most studies, lack of cost and benefit data to assess the suitability of GRs to local conditions is a highly cited obstacle [25]. In the absence of such data, the adoption of GRs poses certain risks to the public, and doubts about their reliability may prevent the acceptance of the technology. In fact, many social

and environmental benefits of GRs are not easily quantifiable in economic terms and are not considered by investors in their decision-making process. However, a number of studies using cost-benefit analysis have shown that the application of GRs is feasible for owners considering environmental and social benefits [46]. From this perspective, it is important to recognize non-monetary benefits of GRs in the formulation of public policies. At present, as a mitigation measure of urban heat islands, GRs have been included in the evaluation standards of green buildings in China, but they cannot fully reflect the environmental benefits of GRs. Thus, a comprehensive performance rating system for GRs should be developed for local governments to establish unified performance requirements, like the rating system and resource for GRs and walls ("LAPT") in North America. However, the difficulties in adopting evaluative policies lie in their complex calculation and professional software development [24]. In view of this, those policies are recommended to be implemented in the mid-to-long term of GR development in China.

4.3.3. Assistance Policies

Assistance policies provide technical support and promotion for GR research and construction, including organization policies and information policies, and are supplementary to mandatory and incentive policies. Organization policies contribute to deal with practical problems of GR implementation and to innovate technologies [24]. In countries with well-established GR industries, nongovernment registered voluntary associations play an important role in the development of GRs, e.g., EFB, FLL, GRHC. Nongovernmental organizations have significant public welfare characteristics, which can coordinate stakeholders, formulate policies, compile standards and codes, and organize academic meetings. Moreover, the professional training provided by those organizations are indispensable for GR development [24,47]. As a response, organization policies are suggested to start in the mid-term of GR development.

Knowledge is the jumping-off point for sustainable practices [12,48], and social acceptance has become the critical driver of technology [25]. Based on previous research, lack of information, awareness and professional knowledge are obstacles to adopting GR technology [49,50], which can even eliminate the effectiveness of incentive policies. There is a significant difference in the knowledge system of GRs between China and the Western countries. Most of the existing research was carried out in developed countries, which accounts for 66% of the total research [51]. The research in developing countries is very limited, which hinders promotion of GRs. For these obstacles, the implementation of mandatory regulations regarding GRs cannot increase stakeholders' enthusiasm and may even cause dissatisfaction. Conversely, information policies can solve this problem through event promotion, information release and experience sharing [24,28], and flexibility is their outstanding advantage [40]. For these advantages, it is recommended to have information policies throughout the roof greening process.

5. A Framework of Green Roof Policies in China

5.1. Policies at Various Levels of Government

From the perspective of international experience, city, state, and even nationwide combined policies may be more effective due to promoting increased awareness at the macroscopic spatial scale [4]. State policies can authorize the control of high temperatures, stormwater, or other types of environmental protection, and local governments can encourage GR implementation as a measure to achieve environmental protection goals in suitable locations or specific circumstances (e.g., high-density urban areas with high rooftop area and impervious area) [26].

5.1.1. State Level

Currently, most ecosystem services lack a market due to the absence of a proper monetization tool [25]. In this circumstance, land development is likely to ignore the regional hydrological features

and violates the concept of sustainable development. Therefore, it is suggested that a state law that requires planning and development consistent with the hydrological features of the regional landscape be adopted. Spatial planning, water resources management and environmental protection need to be placed under the unified management of state institutions [25]. Meanwhile, different policies shall be formulated in accordance with climatic conditions (prioritizing zones III, IV, and V in China's building climate zoning) and economic development (prioritizing national central cities).

5.1.2. City Level

In China, local governments are responsible for functions related to land management, policy-making and development control [32]. In addition, the State Council's institutional reform also clearly proposed that provincial and below institutions should be given more autonomy to strengthen local governance. Therefore, city policies play vital roles in GR implementation. Due to the different local conditions of each city, GR policy is not a one-size-fits-all solution. Under the unified guidance of state policies, city policies should follow the principle of "unification of big policies, difference of small policies" and will vary from the location and goals of the jurisdiction [4,26,49]. To implement policy efficiently, the study of local climate and the socioeconomic context is necessary to be able to use specific, realistic and preferred solutions according to the main environmental problems and development goals of each city [49]. Additionally, from a fiscal perspective, some direct methods are not feasible in fiscally conservative cities, and indirect incentives may fit better [4,28].

5.2. Implementation Framework for Green Roof Policy

Realizing the success and benefits of a policy implementing GRs may be a long process. Therefore, the aforementioned discussion on GR policies has been developed into a framework for guiding GR development in China. This study divides the implementation of GRs into three stages, namely, the pilot exploration stage, the progressive promotion stage and the overall application stage (see Figure 5). In each stage, different policies are implemented according to the targets of the stage, and the policies can be adjusted based on the different development stages of the city. For example, in the context of the current imperfect tax system in China, direct financial subsidies can be used in the near future, and policies such as tax deductions and low-interest loans can be considered in the long run.



Figure 5. Implementation framework for green roof policy in China.

5.2.1. Pilot Exploration Stage

In the pilot exploration stage, guiding, financial and information policies are mainly recommended to encourage stakeholders to accept and adopt GR technologies. This stage pays attention to demonstration of pilot projects, and gains wider experiences ranging from easy to difficult. The guiding policies provide guidance for long-term GR implementation, financial policies are conducive to solve the high costs, information policies respond to threats from the lack of knowledge and suspicion. These policies are easy to implement in pilot projects due to their small scale, although they will develop slowly, initially owing to the lack of awareness and experience of GR implementation [24]. Accordingly, this stage should concentrate on solving policy issues arising from the GR implementation.

5.2.2. Progressive Promotion Stage

In the progressive promotion stage, GRs will become a mandatory requirement, and the mandatory and financial policies will play major roles in promoting GRs to a large extent. Meanwhile, the experience accumulated in the pilot stage can be used for a wider range and more types of buildings. With the increasing public awareness of GR renovation, GR technology has also been improved, which can be easily adopted due to increased awareness and various benefits of GRs. More than anything, it is necessary to regulate the GR policies to ensure GRs follow a standardized and scientific track, and provide guidance for GR promotion.

5.2.3. Overall Application Stage

In the overall application stage characterized by standardization, evaluative policies and organization policies are crucial policies to regulate the national GR market. During this stage, large-scale implementation and mature technology will reduce costs through economies of scale [24]. In addition, technological innovation is closely related to policy support, so it is necessary to further explore the relationship between technology and policy to promote the sustainable development of the GR market.

6. Discussion

6.1. Enlightenment of International Green Roof Policies

As previously mentioned, financial incentives and legal obligations are the most widely-applied international policies, while GR policies in almost every continent are lacking variability, just as the research of Liberalesso et al. [31] found. In Europe, the vast majority of GR policies are financial subsidies. Asian policies focus on legal obligations and financial subsidies. However, in South America, the main policy is property tax reduction, and there is no financing policy for GRs. South American countries do not have the same social and economic conditions and market forces as developed countries. In these countries, funds can be used in other areas as a priority. In this context, GR promotion puts emphasis on policies that do not require direct financial investment, such as mandatory requirements or tax reductions. Therefore, cities with relatively conservative finance can give priority to such policies. Relatively speaking, the GR policies in North America are more comprehensive, including financial subsidies, legal obligations, tax reductions and sustainable certification. Consequently, the GRs in North America have developed rapidly in recent years, while there is no tax reduction policy for GRs in Asia. It is worth noting that stormwater fee reduction policy in North America has become more common after the Environmental Protection Agency implemented the regulations allowing stormwater charges in the US. In view of this, improving tax policy may be a prerequisite for other cities to promote GR development by tax reduction [31], especially in China with an unsound environmental protection tax collection system. In addition, the policy of flexible administrative process is the least, which is not available in Asia and Europe, and needs to be taken seriously.

6.2. Characteristics for Successful Implementation of International Green Roof Policies

Currently, the international GR policies overview successfully implementing GRs indicates the adoption of policies requires some necessary conditions, such as policy foundation driven by environmental issues, targeted area for GRs, and active advocacy by nongovernmental organizations, which is consistent with previous studies [26,33,34]. GR policies are always driven by some urban environmental issues, among which, the three main issues are urban heat island effect, the impact of urban stormwater runoff and the lack of green space [26]. GR initiatives usually lack political basis without the drivers. Moreover, a main characteristic of adopting GR technology for environmental problems' mitigation is that achieving the maximum benefits is limited by the application site. The most effective areas for GR policies are usually high-density urban areas that often correspond to a high rooftop area and impervious area. In areas with less urbanization, other measures may be easier to implement. In addition, the GR policies in Europe and North America were initiated by a small group of people. In North America, GRHC has organized large-scale international GR conferences and developed GR policies in various jurisdictions. In Germany, the FLL prepared the way for GR construction and policy innovation, and the GR guidelines that it has developed have become reference standards for other countries.

6.3. The Influence of Local Conditions on the Development of Green Roof Policies

As consistent research has shown, the presence or absence of appropriate policies can have a significant impact on the effective implementation of green infrastructure (including GRs), and the uniqueness of China's condition directly affects the applicability of international GR policies [24,26,28,31]. Since the development of GRs in China is still in its infancy, policy-making should be tailored to the climate conditions, financial characteristics, urban construction, and policy circumstance of each city. In terms of the scope of implementation, from easy to difficult, priority is given to areas in zones III, IV and V with warm climate conditions in China's building climate zoning, and areas with a good foundation for economic development (e.g., national central cities) for pilot promotion. From the perspective of administrative hierarchy, state policies can authorize the control of environmental protection, and local governments can encourage GR implementation as a measure to achieve environmental protection goals. As for policy details, China's current GR policies are ineffective. On the one hand, the policy system needs to be established (GR policies lack top-level system design), and on the other hand, policy details need to be improved (China's GR policies are outdated compared to Europe and the US). To tackle with the issue, this study proposes a combination of mandatory, incentive, and assistance policies. Of these, mandatory policies are the most effective ones, especially for new urban development projects. However, they may be politically unpopular and their current application is usually in public buildings with few interest disputes. Moreover, the costs lead to inefficient enforcement. For this, mandatory policies should be complemented by other policies (e.g., financial policies), and offer a variety of compliance options which make it easy to implement policies. The financial policies of incentive policies are the most effective way to form a long-term mechanism for solving environmental problems so far, but for some fiscally conservative cities, a direct approach is not feasible and indirect incentives that do not require an additional budget may be more appropriate. From international experience, nongovernment registered voluntary associations are indispensable for GR development. Last but not least, GR policies are not a one-size-fits-all solution for each city, as they can be implemented individually or in combination with each other to meet the needs of each community.

7. Conclusions

Due to land shortages, consumption of energy and resources, and the deterioration of environmental problems caused by the rapid urbanization process, GRs are considered important during the urban development in large high-density cities. Although GRs have been widely applied in some areas throughout the world, their development is lagging in China. Policy-making is crucial to facilitate the implementation of a technology, especially where the technology is still in its early stages of development. Therefore, it is necessary to establish the policy framework that will facilitate the adoption of sustainable strategies for GRs, taking into account the local conditions in China. This study conducted a comprehensive literature review of international GR policies, and analyzed GR policies

in four continents (Europe, North America, South America, and Asia). In the extensive analysis, it was found that most of the GR policies were concentrated in Europe and North America, and many scientific researches in recent years had been conducted in these regions. In summary, there is a lack of policy variability in all four continents, with North American policies being the most comprehensive. The financial incentives and legal obligation are the most widely applied international policies, and the legal obligation is a GR policy adopted on all four continents.

While the experiences of countries around the world in GR-promoting can be a useful reference for Chinese policy-making, China's unique national conditions may make some of these experiences less applicable. Therefore, understanding the characteristics and impacts of various GR policies, and adapting them to local conditions, is key to developing a policy framework for GRs in China. Through a systematic analysis of international GR policies, and considering the local conditions and characteristics of China (climate conditions, economic development, urban construction, and policy circumstances), 23 suitable policies were recommended for China, which were divided into three categories and seven subcategories, including mandatory policies (legislative policies and regulatory policies), incentive policies (guiding policies, financial policies, and evaluative policies), and assistance policies (organization policies and information policies). The applications of these recommended GR policies in China were further discussed; based on the attributes, the policies were developed into a framework that combined the three development stages of GRs (i.e., the pilot exploration stage, the progressive promotion stage and the overall application stage), and can be adjusted based on the different development stages of the city. The findings can help governments develop strategic plans for future GR development, promote the construction of GRs and the improvement of urban ecological environment, and provide a reference for GR research.

In this study, some international policy details were missing to a certain extent due to the unavailability of detailed information on the process from development to implementation of GR policies in some countries, which are crucial for the smooth implementation of the policy framework, and this is the limitation of this study. However, with the continuous promotion of GR technology and the improvement of the information sharing system, it will be more convenient to obtain comprehensive and detailed conclusions to guide the development of policy framework, and implementation on the ground. In a future study, with the gradual implementation of GRs, the relationship between GR policies and the number of GRs can be further researched to investigate the effectiveness of various kinds of local policies for GRs, and on this basis, adjust and systematize policy details. In addition, as our survey is focused on Chinese cities, the GR policy framework is more suitable for China. However, our review of existing literature in non-Chinese cities demonstrates that the problems associated with urbanization processes are similar in different places, and most obstacles and solutions are global. Due to this, with the site-specific adjustments, the findings should also provide important insights for non-Chinese cities, and information sharing on successful green roof policies can help other cities implement more effective policies.

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