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ARTICLE

Research and Experience Reference on London's Response to Climate Change in the Twenty-first Century

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ABSTRACT

London's approaches to tackling climate change after the 21st century are multifaceted and relatively systematic. The aim of this research paper is to analyse London's actions in response to climate change and to draw out what valuable lessons London has for the world in terms of its response to climate change. This paper provides an in-depth analysis of London's policies and actions on climate mitigation in the areas of "greenhouse gas emissions" and "energy infrastructure", and climate adaptation actions in the areas of "city green belt and urban afforestation", "UHI and thermal crisis management" and "water supply infrastructure and sustainable drainage". It then examines the positive aspects of these actions to determine what London has to say about climate change to the rest of the world and other cities. This paper also discovers that to effectively mitigate and adapt to climate change, London has not only established carbon reduction targets, but also created a large academic research network, represented by the LCCP. At the same time, London has developed a scientific climate change adaptation planning framework (P2R2) that focuses on four key areas: Economic, environmental, health, and infrastructure sectors, and three types of risks: Flooding, heat, and water supply, and emphasizes the dynamics and flexibility of each adaptation strategy.

Keywords: Greenhouse gas reduction; Urban green belts; Urban heat island effect; Water supply; Sustainable drainage

1. Introduction

After the turn of the twenty-first century, London has taken several significant studies and actions to combat climate change. On the one hand, mitigation strategies are implemented mainly as "greenhouse

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gas emissions" and "energy infrastructure", such as zero carbon emissions in the building, development industry and energy utility optimisation, and energy monitoring with guidance documents such as the *London Plan 2021*, *Building Regulations*, *London's Plan for 2021*. The other hand is the adaptation to climate change, which includes "urban green belts and afforestation", "thermal crisis management", and "sustainable modifications to water supply and drainage".

With its proactive and multifaceted approach to climate change, London has set an example for cities around the world. Particularly, it has gained a great deal of successful experience in dealing with climate change, particularly in the areas of policy formulation and government planning, climate mitigation and climate adaptation via both mitigation and adaptation strategies. Therefore, the purpose of this paper is to summarise London's successful experience in the previous three areas and to actively assist other cities in addressing climate change issues.

Consequently, the purpose of this paper is to examine the policies and actions that London has developed and implemented in response to climate change, both in terms of mitigation and adaptation, and to analyse and summarise the positive impacts of these policies and actions, as well as the valuable lessons that London can teach the rest of the world about addressing climate change. First, the paper establishes the context for London's response to climate change post-21st century. The paper then discusses mitigation actions in the areas of "greenhouse gas emissions" and "energy infrastructure" as well as adaptation actions in the areas of "green belts and urban afforestation", "UHI and thermal crisis management", and "water supply infrastructure and sustainable drainage". The paper then summarises the positive effects these actions have had on London and the lessons the rest of the world can learn from them. Finally, the paper concludes with conclusions.

2. Background

As a pioneer among developed nations in combating climate change, the United Kingdom was the first nation to respond to the call for sustainable development made at the Rio Global Environment Summit in 1994 with the creation of the country's first "Sustainable Development: Strategic Choices for Britain" to address the escalating issue of climate change [1]. With the 2008 *Climate Change Act*, the United Kingdom became the first nation in the 21st century to legislate medium- and long-term emission reduction targets. The United Kingdom signed the Paris Agreement seven years later. The target is to keep the increase in global average temperature below 1.5 °C above pre-industrial levels (above 1.5 °C, the risk of climate change will threaten humanity's survival) [2]. The United Kingdom has subsequently incorporated temperature increases into its response strategy.

London, as the capital of the United Kingdom in the 21st century, has implemented several policies to address the growing challenges of climate change in terms of carbon emissions, energy demand, waste pollution, and the heat crisis, reorienting the city's economic and environmental sustainability strategies and implementing several actions to combat climate change to achieve these global and national objectives. In 2018, it published *The London Environment Strategy*, the first strategy document for a global city that meets the highest goals of the *Paris Agreement*, which outlines objectives and initiatives in both climate mitigation and climate adaptation (e.g., creating a zero-carbon city) [2]. This paper will therefore focus on the first two aspects of London's response to climate change in terms of its actions and inspirations.

3. Actions to climate change

The section that follows will first describe specific actions and policies for mitigating climate change in London from the perspectives of "greenhouse gas emissions" and "energy infrastructure", and this essay also uses **Figure 1** to show all the mitigation actions and policies to climate change in London. The subsequent section of this article will describe specific actions and policies to adapt to climate change in London from the perspectives of "urban afforestation and city green belts", "UHI and thermal crisis

management", and "water supply infrastructure and sustainable drainage", and this essay also use **Figure 2** to show the all the adaptation actions and policies to climate change.

3.1 Mitigation to climate change

Greenhouse Gas Emissions

The UK is the world's eighth largest emitter of carbon dioxide, with London accounting for 8.4% of these emissions [5]. To mitigate climate change, London's first action is to minimise greenhouse gas emissions in the city. In this regard, London has launched a number of climate change mitigation and energy policies and actions, including the *London Plan 2021*, *Mayor's Climate Change Adaptation Strategy Managing risks and increasing resilience*, *Climate Action Strategy 2020-2027*, new *London Declaration*. In 2011, London first set a target of a 60% reduction in emissions by 2025 compared to 1990. In order to achieve this, the *Mayor's Climate Change Adaptation Strategy Managing risks and increasing resilience* plan requires the government (the Mayor) to prepare a climate change mitigation strategy [7]. Under this obligation, the mayor ensured that all future GLA (Greater London Authority) plans and strategies would consider how to reduce carbon emissions. Nine years later, the Climate Action Strategy 2020-2027 identifies specific actions to reduce emissions in London by improving the urban environment [8]. That is, reducing emissions in the public realm by increasing green spaces, urban greenery,

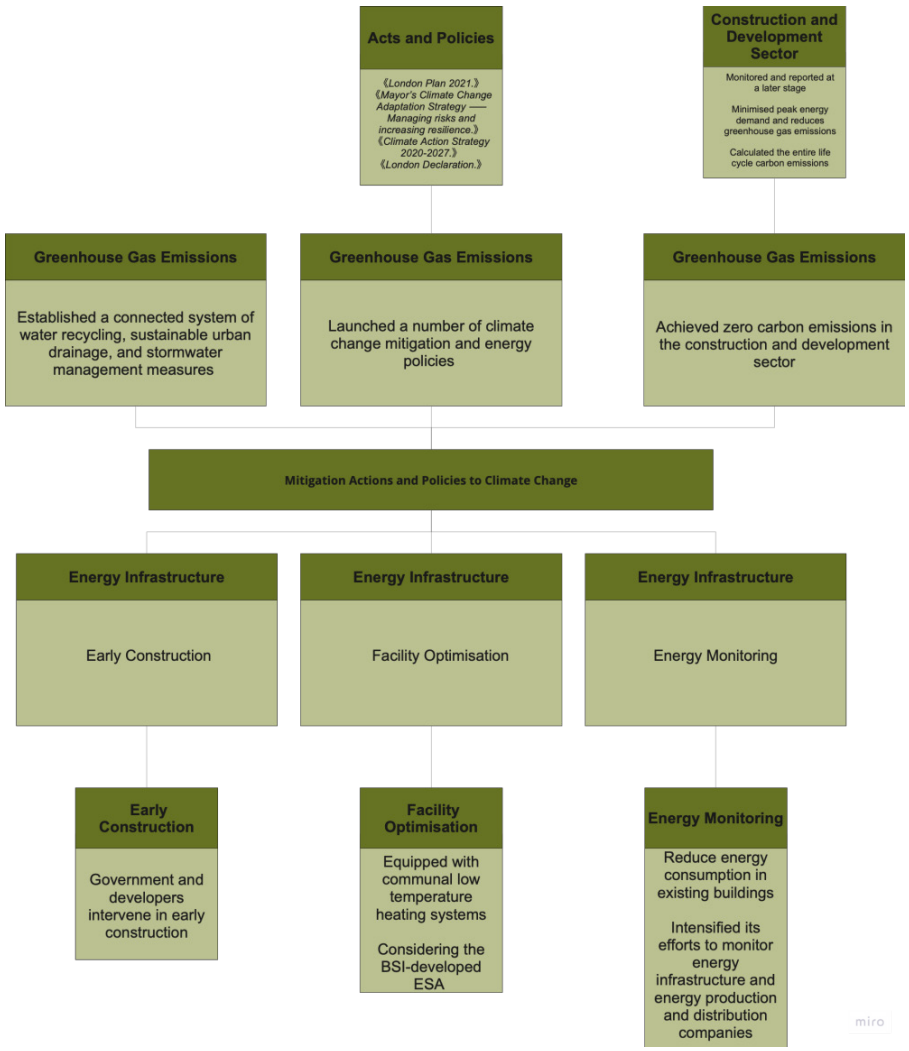

Figure 1. The framework of mitigation actions and policies to climate change.

flood-resistant pavements, adaptive planting systems and heat-resistant materials. At the same time, a connected system of water recycling, sustainable urban drainage, and stormwater management measures to promote greenhouse gas absorption and transformation are being developed through the development of sustainable stormwater and surface water management policies.

London's recent *London Plan 2021* draws on government functions to outline specific actions for the construction and development sector to achieve zero carbon emissions in three areas [4]. Initially, it is proposed that the pre-project operation procedure minimises peak energy demand and reduces greenhouse gas emissions in accordance with various energy hierarchies. Second, the in-situ emission reductions throughout the duration of the project should be at least 35% greater than those mandated by the Building Regulations. Energy efficiency measures should reduce emissions by 10% more than required by the *Building Regulations* for residential development and by 15% more for non-residential development [4]. Plans submitted to the mayor should calculate the entire life cycle carbon emissions using a full life cycle carbon assessment and demonstrate the measures taken to reduce life cycle carbon emissions. Thirdly, energy performance must be monitored and reported at a later stage of the project, such as through the display of energy certificates and online reporting to the mayor for at least five years [20]. The BSI (British Standards Institution) launched the new *London Declaration* in the same year to promote climate-friendly standards as the norm for all industries by publishing practical guidance to assist an increasing number of industries in achieving net-zero emissions. For instance, the BSI and others have developed detailed production standards for the UK battery industry to help the rapidly expanding battery production, recycling, and research sectors of the business collaboration in a manner that reduces emissions and is more sustainable [6].

In recent years, the majority of new developments and construction projects in London have actively contributed to the reduction of CO_2 emissions. In 2016, the construction industry acted. There is a clear hierarchy of energy requirements and CO_2 emissions for all types of buildings, plants, and equipment, as dictated by the *Building Regulations* [4]. In addition, the industry is reducing emissions through the design of energy-efficient sites, buildings, and services. And, where feasible, emissions are reduced further using decentralised energy sources, such as district heating and cooling and CHP (Combined Heat and Power) renewable energy technologies [5].

Energy Infrastructure

Three main areas of climate change mitigation are prioritised in London's energy infrastructure strategies: Early construction, facility optimisation, and energy monitoring. First, the *London Plan 2021* recommends that the government and developers intervene in early construction to anticipate future energy infrastructure requirements and to develop energy master plans for major developments in order to determine the most efficient energy supply options. Simultaneously, major developments within the planned heat network priority areas should be equipped with communal low temperature heating systems, such as zero-emission energy or local secondary heat sources, to mitigate climate change and improve energy supply security [4]. London has responded to the UK Government's energy transition programme by considering the BSI-developed ESA (Energy Smart Appliances) standard for the operation of energy facilities. It is planned to install smart appliances throughout the city to make electricity demand more responsive to the availability of renewable energy. By engaging consumers in the demand management of the electricity system, we can expedite the achievement of net-zero emissions [6].

Thirdly, London has optimised late-stage energy monitoring to, the one hand, reduced energy consumption in existing buildings. On the other hand, climate change has in recent years reduced the demand for heating (natural gas) in winter and increased the demand for cooling (electricity) in summer in the city. As a result, London has intensified its efforts to monitor energy infrastructure and energy production and distribution companies [7] to ensure that their

systems are climate-resilient and able to meet seasonal changes in energy demand. New facilities are also required need to be flexible to changes in waste production and resilient to the effects of climate.

3.2 Adaptation to climate change

City green belt and urban afforestation

London views the Green Belt as a climate safety belt to protect its citizens from extreme weather conditions. In recent years, London has adapted to climate change primarily through the Green Belt's provision of carbon sinks and other ecosystem services. Based on the existence of several abandoned sites in the Green Belt that contribute positively to biodiversity, flood prevention, and climate resilience through reuse, specific actions are proposed. And to collaborate with districts and other strategic partners to advance the joint development of ecological services within the Green Belt. Simultaneously, well-managed forested catchment areas can be used to offset the carbon implied and generated by urban areas and to enhance these areas in a manner consistent with the development of London's Green Belt. Second, London developed a specific cross-sectoral Green Belt for climate change adaptation in 2008, implementing adaptation measures while Green Belt and compact city policies gradually restrain urban growth [9]. The Green Belt has acted as a restraint on compact development within cities while easing non-compact planning on the urban periphery. Consequently, with more extreme weather events, London's Green Belt is essential for mitigating climate change, such as rainfall and flooding, as well as reducing heat from the urban heat island effect [10]. Thirdly, London is professionally accountable for Green Belt development by establishing a management company. The City of London Corporation, as the largest manager of the Green Belt, currently oversees more than 35,000 acres of green space. This is equivalent to approximately 5,500 football pitches (removing approximately 16 kt of CO_2 per year, which is 40% of the total emissions of London's boroughs 1 and 2) [8].

Simultaneously, London has improved its urban greenery through the implementation of initiatives

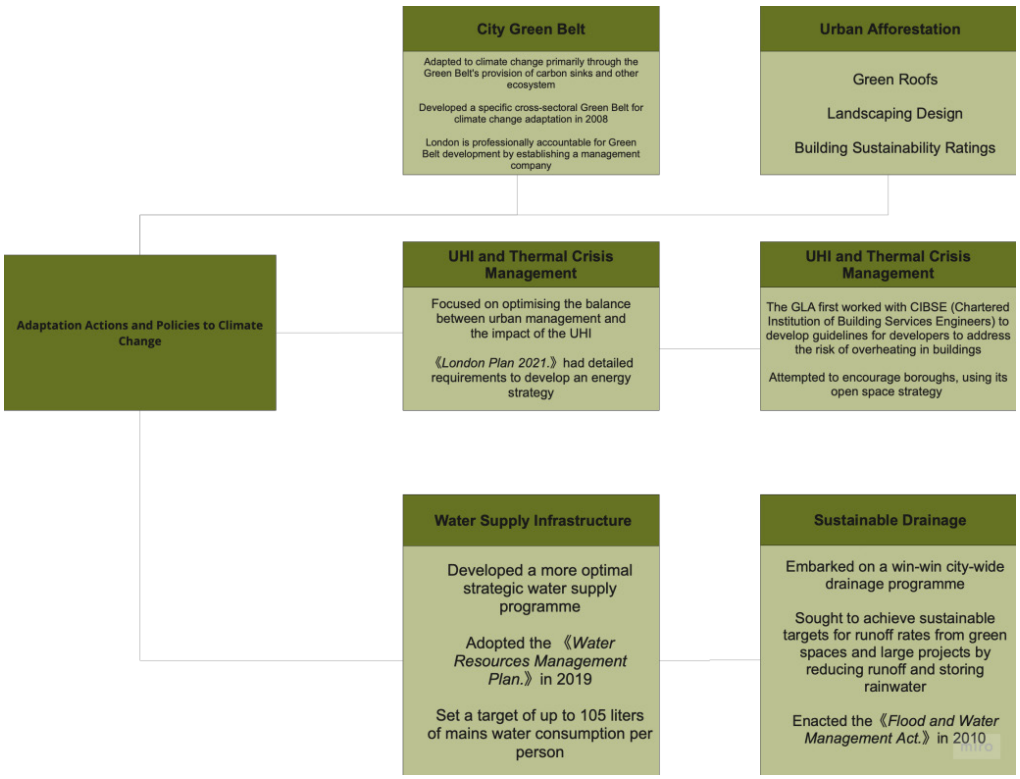

Figure 2. The framework of adaptation actions and policies to climate change.

such as green roofs, landscaping, and building sustainability ratings. Square Mile currently manages approximately 42,600 m^2 of London's green roofs (up from 11,200 m^2 in 2005) and plans to increase this to 65,800 m^2 by 2024. Green roofs absorb approximately 55 percent of the CO_2 emissions from new buildings in zones 1 and 2 of London. Increase the amount of green space and vegetation in London, particularly in Central and East London [7] in terms of landscape beauty. This is because, during warm weather, the prevailing wind is from the east, warming the air as it passes through the city. Keeping East London as green as possible helps to maintain the cooler temperatures in Central and West London. Simultaneously, launch an urban landscaping campaign, including in the east, to identify, prioritise, and implement opportunities to increase green space coverage, and to include the UHI (Urban Heat Island) map in the planning of a London-wide green grid. Thirdly, sustainability is becoming an increasingly important factor when considering the climate adaptation of new buildings, with the majority of buildings being rated for sustainability using BREEAM, the most well-known green rating system in the world. According to recent research by BREEAM creators Knight Frank and BRE, however, London office buildings that meet the most stringent sustainability standards can command rent premiums of up to 12.3% [12]. In recent years, London building developers, represented by the City of London Corporation, have endeavoured to achieve a BREEAM "Excellent" rating for nearly 75% of their new commercial developments (over 20,000 m^2 in terms of floor space) [8]. Additionally, major development applications must contribute to London's urban greenery, including urban greenery as a fundamental element of building and site design. London boroughs have established a UGF (Urban Greening Factor) to determine if new developments contain adequate urban greening.

UHI and Thermal Crisis Management

The heat crisis represented by the UHI has become another major challenge to London's adaptation to climate change in recent years, a phenomenon where urban temperatures are higher relative to surrounding rural areas due to, among other things, urban ground, and anthropogenic heat sources. Compared to the average urban temperature difference of 3-4 °C, central London is up to 11 °C warmer than the surrounding green belt (2003) [7]. In response to the increasing average temperatures in London, the GLA first worked with CIBSE (Chartered Institution of Building Services Engineers) to develop guidelines for developers to address the risk of overheating in buildings [5]. Considering the location of the development in relation to the urban heat island, the guidelines focus on recommending that the adverse effects of UHI should be minimised through the design, layout, positioning, materials, and incorporation of green infrastructure. Examples include installing directional, shading, and high albedo materials; opening windows, insulating, and providing green infrastructure to reduce the amount of heat entering the building; or prioritising the provision of passive and mechanical building ventilation; incorporating cooling hierarchies into the design process to better manage their cooling needs and adapt to climate change and so on [26]. Second of all, in *London Plan 2021*, there are detailed requirements for major building projects to develop an energy strategy that demonstrates that the scheme will reduce the potential threat of excessive internal heating or cooling. For example, reducing the internal heating demand of buildings through designs that increase energy efficiency, reducing heating demand by green infrastructure and new materials, etc. [23].

Meanwhile, London has attempted to encourage boroughs, using its open space strategy, to adapt to climate change by protecting local green infrastructure and the ratio of green space to buildings. UHI is largely caused by the absorption of solar energy by the urban fabric. Meanwhile, the reflectivity of the radiation is mainly determined by physical properties of the buildings and increases the frequency of conditions that lead to heat island creation. The absorptive capacity and share of London's green spaces are therefore even more important. At the same time, the ratio of green space to buildings clearly affects

the intensity of the UHI [7]. Referring to model simulations from the Lucid Research Project in London [9], UHI intensity increases as the relative proportion of green space to non-green cover decreases, with each 10% increase in non-green cover increasing UHI intensity by 0.5 degrees Celsius. Removing green space will increase temperatures by 2-3 degrees Celsius. Thirdly, London has in recent years focused on optimising the balance between urban management and the impact of the UHI, the parallel demands of water use and carbon emissions, and thus reducing the negative impact of the UHI. For example, the BRIDGE75 programme, which focuses on central London, aims to provide advice on how and where to maximise the use of government managed to reduce the negative impacts of the UHI, such as increasing the demand for water to maintain vegetation and capturing air pollutants in street canyons [5].

Water Supply Infrastructure and Sustainable Drainage

In relation to London's water needs in recent years, as mentioned above, London has tried to adapt to the changing climate by seeking breakthroughs and progress in water supply and drainage. In terms of water supply, London's main efforts have been to protect and conserve water supplies and to secure demand for use in a sustainable manner. Firstly, Thames Water has in recent years developed a more optimal strategic water supply programme through the water management planning process, including the development of potential new reservoirs, effluent reuse, water transfers and the development of new groundwater sources [11]. The programme should also promote improvements to water supply infrastructure in a timely, efficient, and sustainable manner, considering security of supply and energy consumption. Secondly, to complement the water supply programme and current supply needs, London adopted the *Water Resources Management Plan* in 2019, which retains a large number of the original and efficient water supply infrastructure developments. And the London Government also supports the development of additional water sports centres or related new infrastructure on a pre-existing basis where boroughs have locally identified water supply deficits and where the infrastructure does not have a negative impact on navigation or waterway protection [25]. Thirdly, for new residential developments designed in the city in recent years, London has also set a target of up to 105 liters of mains water consumption per person per day, and to minimise mains water use, building interiors are simultaneously required to protect and conserve water supplies and resources in a sustainable manner [7].

In terms of drainage, London has made sustainable changes mainly based on its own geography and rainfall characteristics. According to the latest Mayor of London statistics, London currently receives more than two feet of rainfall per year. London has therefore first embarked on a win-win city-wide drainage programme for the collection and use of rainwater for non-consumptive purposes, for example using rainwater for part of its domestic use (watering, car washing, etc.) [26]. This reduces the need for water treatment, the pressure on the drainage network (and therefore the risk of flooding), while reducing the volume of diluted wastewater to be pumped to and treated at a sewage treatment plant [7]. Secondly, London seeks to achieve sustainable targets for runoff rates from green spaces and large projects by reducing runoff (e.g., sustainable drainage systems) and storing rainwater (e.g., rainwater harvesting systems). The GLA, Thames Water and the Environment Agency have worked together to identify a "sustainable drainage rating" policy to encourage sustainable drainage. This rating, which initially had a positive impact on large developments, has been applied more recently to smaller sites and infill developments, considering relative cost effectiveness, delivery mechanisms, barriers to implementation, and adaptation pathways [7].

At the same time, London's variable climate means that it is more difficult for local authorities to predict areas at risk of surface water flooding, compounded by London's particular geography, which exposes it to year-round summer convective storms and therefore often has the most unpredictable localised drainage capacity. As a result, London

enacted the *Flood and Water Management Act* in 2010, which details how boroughs can establish mechanisms to identify surface water management and develop measures and policies to reduce risk [23]. Meanwhile, for low-lying transport infrastructure (e.g., lower parts of the London Underground network), London's options for managing rainfall runoff include not only the capacity of local drainage systems, but also an additional 12,000 km of roads and footpaths, thus providing an extensive impermeable surface to prevent surface flooding and respond to variable climate change. The aim is to use an optimised drainage network to bring rainfall to the 30-year level.

4. Effect of actions

In the following section, the paper will analyse each of these actions in a relatively positive light, based on the above-mentioned actions of London in terms of mitigation and adaptation, to determine the impact each of these actions has had on London's city and society. This will allow for a clearer understanding of what London's actions in response to climate change over the past few years have taught the world and other densely populated cities.

4.1 Mitigation to climate change

In the face of the climate challenge, London is starting to mitigate climate change by reducing greenhouse gas emissions. Achieving minimal greenhouse gas emissions. This has had a twofold positive effect. On the one hand, London is first reducing emissions from public spaces by increasing urban green spaces, using heat-resistant materials, and developing sustainable drainage systems. This will not only enrich the urban ecosystem and increase urban green space. Priority was also given to addressing sources of air pollution, reducing people's exposure to bad air (children) and improving people's quality of life [25]. On the other hand, by initially requiring the construction and development sector to reduce emissions, London has firstly optimised the process of reducing carbon emissions in the construction sector (pre-project operation, low emission reduction in the middle of the project, and post-project monitoring) and accelerated the transition to low carbon integration in other sectors. Secondly, the process of reducing emissions from construction has significantly strengthened the partnership between government and other partners due to the large number of stakeholders involved in the construction sector [26]. The introduction of documents such as the *Building Regulations* has reinforced the role of mayors and government leadership in climate change. Thirdly, energy efficiency in buildings is being upgraded through energy ratings, low carbon technologies and services, and the energy efficiency of existing and new buildings is being improved, accelerating the city's shift towards a preference for renewable energy. Fourthly, the combination and use of district heating and cooling, CHP and renewable energy technologies optimises the approach to new and viable building and development strategies and upgrades the model for future sustainable urban development.

Meanwhile, the energy infrastructure strategy has had three main positive effects. Firstly, the early construction and intervention of London's infrastructure identify the most efficient energy supply, while efficiently producing energy to meet the city's needs and avoiding energy shortages due to the rapid urban growth of the population. Secondly, the optimisation and transformation of facilities such as the communal low temperature heating system and ESA standards have brought security and reliability of supply to London's energy. The optimisation process specifically involves forecasting the heat and power infrastructure, modifying the built environment to reduce demand, and transporting electricity [24]. Demand shifting and storage options that consider "smart" energy offer significant potential for future energy reserves. And optimising and developing low carbon and decentralised energy supplies. For example, the development of combined cooling, heat and power systems, small-scale renewable energy installations (wind and solar), etc. within the City of London, replacing some of the electricity supplied by the

national grid and significantly reducing losses due to long-distance transmission [13]. Combined with the previously mentioned reduction in greenhouse gas emissions, London's low carbon energy consumption collectively makes a significant contribution to climate change mitigation [21]. Thirdly, late-stage energy monitoring increases the affordability and cost competitiveness of energy. Referring to the arguments of representatives from the electricity and development sectors, London's gas and electricity costs are more competitive, and reserves are more abundant through stronger links with the building sector and energy production and distribution companies [16].

4.2 Adaptation to climate change

The Green Belt brings a wide range of environmental benefits to London's periphery and plays an important role in London's adaptation to climate change. First, the ecosystem services of the Green Belt strengthen the link between renewable resources and nature around the city. These green spaces are reconceptualized as areas that provide a variety of functions of strategic importance for climate adaptation, river management, and management of biodiversity [10]. For example, green belts provide habitat for wildlife around London and provide more opportunities for people to travel and enjoy open land and countryside outside the city. In particular, it provides more land for agriculture to grow to produce healthy seasonal food [16], and a more sustainable and healthier growing environment also drives the local rural economy and employment development. Second, the actions of the Green Belt in managing rainfall and flooding provide multiple ecosystem benefits to different types of open space around London, including urban cooling, improved air quality, flood protection and carbon sequestration (especially in woodland areas), and local food production [15]. In recent years, non-compact planning has similarly evacuated inner-city London from residential and demographic pressures. In addition, the creation of a dedicated Green Belt authority has played a crucial role in absorbing carbon emissions around London, reducing waste and supporting the circular economy. In recent years, documents such as the *London Plan 2021* have also set out action targets for the simultaneous development of a circular economy, calling for a meeting or exceeding London's target of recycling 65% of its waste by 2030 [23]. As a result, thousands of acres of the green belt can absorb huge amounts of carbon dioxide and waste each year and dispose of it naturally through land decomposition, green plants, etc. Such treatment substantially reduces the potential variation in the amount of waste within the city, significantly shortens the process and time from waste collection to treatment and final disposal, and simultaneously promotes the development of an internal and external urban cycle and circular economy [7].

In terms of urban greening, the actions undertaken in London to adapt to the climate have brought similarly positive results. First, the construction and centralized management of green roofs have alleviated the pressure of water stress in London. This is since green living roofs that do not require irrigation have the potential to mitigate the impact of runoff and storm events, thereby reducing negative downstream impacts on drainage infrastructure. Similarly, source control techniques for stormwater management through an integrated approach to active roofs can effectively reduce flood risk by avoiding the increased surface and sewer flooding and flood risk associated with frequent rainfall in London [26]. At the same time, green performance can reduce the absorption of nighttime radiation from buildings and roofs, thus allowing buildings with green roofs to reduce temperatures and the urban heat island effect and receive wider environmental benefits [17].

Secondly, landscaping increases the importance of landscape planning and development perceptions in London, and more importantly, London's environmental quality through appropriate green infrastructure in the landscape. Green landscapes on the one hand can reduce the negative impact of UHI, absorb harmful and greenhouse gases, and reduce air pollution. On the other hand, it can also serve and enhance the cultural identity of London's urban and suburban areas together through the maintenance of the uniqueness of the London landscape, for exam-

ple, by promoting community health and well-being through community gardening [18]. Thirdly, the sustainability rating of buildings on the one hand safeguards the well-being of residents, and the BREEAM assessment covers all aspects of residents' livelihood and well-being from energy, land use, materials, management, pollution, transport, waste, innovative water, health, etc. On the other hand, it also drives the economic vitality of the London development market, driving a positive cycle of economic benefits by giving the project a sustainability edge.

At the same time, in reducing the negative impact of the UHI, London has first acted on materials, major construction projects, etc. from a construction perspective. This has resulted in a significant reduction in building temperatures and avoided air pollutants from the constant high temperatures in buildings, as well as reducing the incidence of heat stroke and heat cramps, heat-related mortality, respiratory problems, and other human health problems in buildings. At the same time, the reduction in building temperatures simultaneously reduces the electricity demand for air conditioning (especially in summer) and avoids urban overload due to excessive electricity use [24]. As well, power plants increase the production of energy from fossil fuels by providing the additional energy required, thus increasing greenhouse gas emissions and air pollutants, including carbon monoxide (CO), carbon dioxide (CO_2), sulfur dioxide (SO_2), nitrogen oxides (NO_x), particulate matter, and mercury (Hg) [19]. And it also slows down global warming and climate change a result. Second, London's use of green infrastructure to absorb temperature and solar energy, on the one hand, substantially increases the ecological benefits of the city; greenery is an excellent insulator in summer, reducing the overall urban heat island effect, and cooling the surrounding environment, further reducing the need for air conditioning from the side. At the same time, with the coverage of green facilities, a large number of plants (open-air planting, street trees and curb planting) are able to absorb CO_2 and produce fresh air, and air quality is improved [25]. On the other hand, the improvement cost of plants is relatively low. Thus, similar practices not only produce cooling effects in urban areas, but also reduce cooling costs. Third, after the London government optimized the management of the UHI, the temperature in the city center continues to decrease through water, the global leader in carbon emissions in a parallel way. This has served as a positive model for other very densely populated central cities.

Fourth, concerted efforts in drainage and water supply have also made London more resilient to climate change in recent years. First, the optimization of water supply and drainage facilities by companies and institutions such as Thames Water protects and improves the environment while securing the investments needed for public water supply and drainage in the region [14], providing London with safe and sustainable water resources. Second, London's water resources are further scarce at a time of dramatic climate change. However, London has introduced a series of policies and bills detailing per capita water consumption, surface water management rules, and other detailed requirements, each of which is more precise and reasonable, and this has truly reduced London's growing water demand and safeguarded residential water sanitation and health. Thirdly, the *Flood and Water Management Act* and other documents that London has introduced in response to its own geography have strongly supported London to better cope with floods, droughts, and extreme heat, providing advice and warnings during extreme heat, cold and flood events, helped and protected Londoners by planning systems to make new developments more efficient in terms of water use and to provide reasonable control of temperature rise and flood risk.

5. Experience reference and discussion

Climate change has become a common challenge for humankind. To cope with climate change, both mitigation and adaptation are needed, and while significantly reducing greenhouse gas emissions, proactive adaptation actions are needed to mitigate the adverse impacts of climate change on natural ecosystems and socio-economic systems [24]. To actively respond to global climate change, London

has accumulated a lot of experience in three major areas, including policy formulation and government planning, climate mitigation, and climate adaptation, which have some valuable insights for other cities in the world to respond in the future. In **Figure 3**, this essay uses the graph to show the summary of experience reference on London's response to climate change.

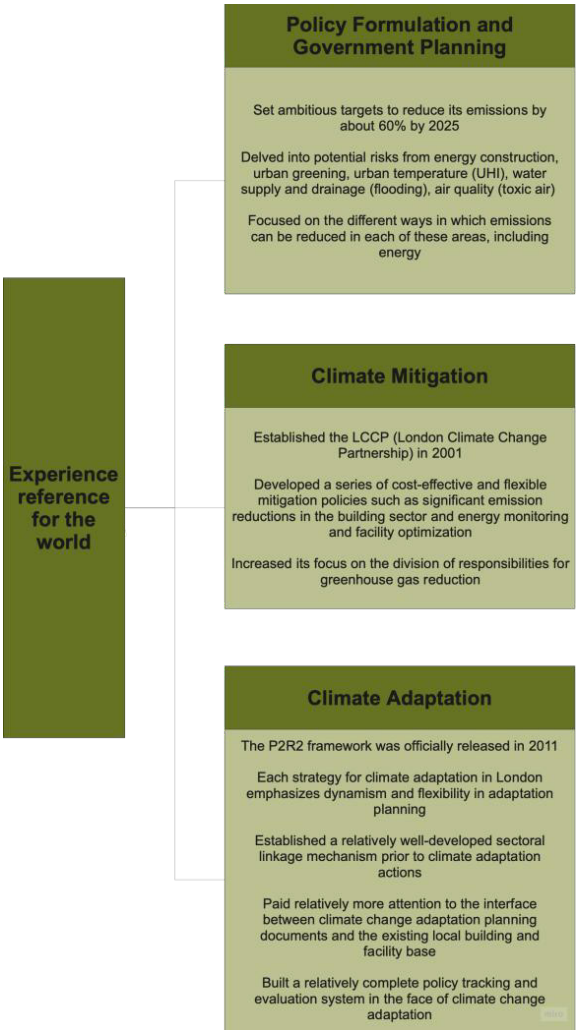

Figure 3. The summary of experience reference on London's response to climate change for the world.

Since 2005, London has developed and implemented policies, targets, and plans to address climate change. Firstly, in terms of low carbon emission reduction, London has set ambitious targets to reduce its emissions by about 60% by 2025 compared to 1990 (19.6 million tons of CO_2 emissions per year) and to achieve zero emissions by 2030. However, the UK's sixth Carbon Budget will incorporate the UK's share of international aviation and shipping emissions for the first time which means it has already achieved the 60% reduction target to some extent [27]. Second, London delves into potential risks from energy construction, urban greening, urban temperature (UHI), water supply and drainage (flooding), air quality (toxic air), and many other aspects to ensure that the city supports low-income people from the cost, and that residents benefit from warmer, energy-efficient homes, cleaner air, and new green jobs from faster action. Third, London looks at the different ways in which emissions can be reduced in each of these areas, including energy [4]. On the one hand, the government is progressively strengthening planning leadership and funding to meet emissions reduction targets and advancing infrastructure planning for energy, green, and drainage hearings. On the other hand, the government has planned and promoted the growth of other aspects of society through the concept of sustainable development and the means to address climate change, based on achieving the net zero target [21]. This includes supporting tens of thousands of jobs, improving health through better air quality and more active lifestyles, reducing inequality, and improving the well-being and quality of life of residents.

London has made great efforts and sacrifices in climate mitigation. First, to effectively mitigate climate change, the Greater London Council established the LCCP (London Climate Change Partnership) in 2001, with a core membership of representatives from over 30 organisations including the council, planning, finance, health, environmental management, climate research, and the media. The partnership has established an extensive network of academic research and information communication through projects and forums and has involved over 200 organizations. Second, London has developed a series of cost-effective and flexible mitigation policies [22] that have led to the active implementation of emission reduction targets in all sectors and all regions of the UK, such as significant emission reductions in the building sector and energy moni-

toring and facility optimization. These policies and measures will secure and strengthen the UK's national competitiveness while ensuring that industry and commerce are served at lower energy costs and alleviating energy fuel poverty, improving air quality in urban areas, reducing adverse health risks, and expanding exports and developing new business opportunities. Third, in terms of greenhouse gas reduction, London has increased its focus on the division of responsibilities for mitigation actions. On the government side, the importance of climate mitigation actions is highlighted through bills and policies, such as the 2008 *Climate Change Act*, the 2020 *Climate Emergency Action Plan* [21] and so on, which clarify the legal obligations of cabinet ministers. In terms of social division of labor, London has adopted the *Building Regulations*, *London Declaration* and other documents that focus on the primary responsibility of the building industry to reduce emissions and set various levels of standards for the building industry. A climate mitigation partnership has been established and promoted to promote the adoption of mitigation measures and to empower key stakeholders (development and construction of major construction and energy projects) to take proactive measures to reduce greenhouse gas emissions and reduce reliance on fossil fuels.

At the same time, London is more representative of climate change adaptation, and its planning proposals for adaptation are considered to be at the forefront of global adaptation action. For a long time, climate change strategies around the world have centered on mitigation, with adaptation policies and actions lagging far behind the process of mitigation. Given the difficulty of mitigating the impacts of climate change in the short term, London has a higher urgency to develop and implement climate change adaptation policies and increase resilience to the adverse impacts of climate change. This has enabled the establishment of a more developed institutional system for climate change adaptation [3]. First, the P2R2 framework, which was officially released in 2011, divides climate change adaptation actions into four levels: Prevent, prepare, respond, and recover. Scientific climate change adaptation plans, action plans, and other planning-type documents, such as the *Draft London Climate Change Adaptation Strategy*, are developed in the initial planning stage [11]. Thus, London can systematically assess the impacts of climate change on London and develop more comprehensive and detailed adaptation actions. Second, each strategy for climate adaptation in London emphasizes dynamism and flexibility in adaptation planning, highlighting future climate change and uncertainty issues in London's development process. For example, London focuses on three categories of climate risks, namely flooding, heat and water supply. Based on the systematic assessment of the first three types of risks, the adaptation strategy proposes specific action plans for each of the four key areas most affected by climate change, the economy, environment, health, and infrastructure [26], and sets up a policy tracking and evaluation mechanism to track and detect the progress and effectiveness of adaptation efforts in a timely manner.

Third, London has established a relatively well-developed sectoral linkage mechanism prior to climate adaptation actions. Within the government, adaptation to climate change requires the establishment of cross-regional and cross-departmental coordination bodies to achieve effective policy communication. For example, the Green Belt, drainage, and water supply sectors all require consistent policy regulation in response to London's floods. Establishing effective communication channels between the government and other stakeholders is a key success factor for adaptation in London, and communication between stakeholders helps to develop scientific adaptation planning and helps to stimulate the participation of all parties [11]. Fourthly, London has paid relatively more attention to the interface between climate change adaptation planning documents and the existing local building and facility base, for example, the reduction of UHI process, most buildings are rated using the new BREEAM thus making sustainability an increasingly important factor for local London office and retail spaces, promoting a shift in London's governance model from emergency manage-

ment to risk management. Finally, London has built a relatively complete policy tracking and evaluation system in the face of climate change adaptation. Policy tracking and evaluation help to keep track of the progress and effectiveness of climate change adaptation efforts and plays an important role in promoting the implementation of relevant policies by various stakeholders [25]. For example, the Sustainable Drainage Rating developed by the GLA, Thames Water and the Environment Agency has been instrumental in optimizing London's drainage system and saving water. In addition, the results of policy tracking and evaluation can help guide adaptation planning in line with the current state of adaptation in London, resulting in long-term dynamic adaptation planning [26]. Adaptation to climate change could consider introducing third-party assessments to provide an objective evaluation of policy implementation and goal achievement.

6. Conclusions

After the 21st century, London, has played a leading role in addressing climate change. This paper discusses the actions taken by London in recent years and the positive effects on urban development from the perspectives of climate mitigation and adaptation. London has gained extensive experience in three key areas: Policy and government planning, climate mitigation, and adaptation for other cities worldwide. First, London has set ambitious carbon emission reduction goals. Simultaneously, London has considered and investigated the potential risks in numerous ways, including energy production from a human perspective. In addition, London has investigated various methods for reducing emissions in each sector, including the application of sustainable development principles and methods for combating climate change. Second, to effectively mitigate climate change, London has established a vast academic research network, represented by the LCCP, which provides crucial support for scientific decision-making. In the meantime, London has developed several flexible and cost-effective mitigation policies, including substantial emission reductions in the building sector. In addition, London has paid more attention to the allocation of responsibilities for mitigation actions in terms of greenhouse gas reduction.

Thirdly, London is better represented in terms of climate change adaptation. First, London has developed a scientific planning framework for climate change adaptation (P2R2) that focuses on four key areas: Economic, environmental, health, and infrastructure sectors, as well as three types of risks: Flood, heat, and water supply, with an emphasis on the dynamic and flexible nature of each adaptation strategy. London has established a relatively well-developed sectoral linkage mechanism and a relatively comprehensive policy tracking and evaluation system established. In addition, London has given greater consideration to the interface between climate change adaptation planning documents and the existing local building and facility base. Addressing climate change provides a socio-economically inclusive and environmentally friendly sustainable development for the city, which necessitates the future collaboration of government, society, business, and community stakeholders.

Conflict of Interest

There is no conflict of interest.

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