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Qualitative comparative analysis of city sustainable strategies: Insights from of 25 global cities

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Abstract

Rapid urbanization and mounting environmental pressures require fresh strategies for sustainable city development. Although research abounds on individual measures, green corridors, compact-city policies, and smart technologies, comparative insights into how these approaches interact are scarce. This study bridges that gap by applying Qualitative Comparative Analysis (QCA) to 25 leading cities, structured around six interdependent dimensions: Ecological Urban Quality (ECOQ), Environmental & Geographic Factors (ENGE), Economic & Financial Conditions (ECOF), Political & Policy Factors (POP), Social & Cultural Dynamics (SOCC), and Technological Innovation (TECHI). Leveraging composite indices and TOSMANA-driven procedures, we identify nine "recipes" for high ecological performance and five configurations tied to underperformance. Findings demonstrate that no single condition guarantees success; instead, the synergy especially between ENGE and POP proves most potent. Case studies of Bogotá and Quito reveal how financial and institutional constraints can stall progress despite strong natural endowments. Moving beyond isolated examples, this research delivers a novel decision-support tool for urban planners and policymakers. It enriches theoretical understanding of conjunctural causation in ecological urbanism and offers actionable guidance for crafting locally tailored policy mixes, advancing more resilient, equitable, and ecologically sound urban futures.

Keywords: Ecological urbanism, Governance and environmental outcomes, Policy configurations, Qualitative comparative analysis (QCA), Urban sustainability.

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1. Introduction

The rapid pace of urbanization has brought unprecedented challenges for cities worldwide: sprawling development, escalating resource consumption, and mounting climate risks threaten both human well-being and ecosystem integrity. As urban populations now exceed half of humanity, there is an urgent imperative to rethink how cities are designed, governed, and managed to ensure resilience, equity, and ecological sustainability. Ecological urbanism the integration of natural systems into urban form and policy has emerged as a powerful paradigm, drawing on foundational insights from McHarg's natural-systems mapping [1] and Jacobs's advocacy for mixed-use, vibrant public realms [2] as well as more recent frameworks such as Beatley's Green Urbanism [3] and Newman and Jennings's sustainable urban ecosystems [4].

Despite a rich theoretical literature and numerous case studies illustrating individual strategies (e.g., green corridors, compact-city policies, smart-city technologies), there remains little consensus on which combinations of environmental, economic, social, political, and technological factors most reliably yield positive ecological outcomes across diverse contexts. Prior empirical work has tended to focus on single metrics or single-city case studies, limiting our ability to generalize findings or to tailor policy mixes to local conditions. Moreover, while methods such as resilience assessments and ecosystem service valuations offer valuable insights, they often overlook the interactive, conjunctural nature of causal conditions in complex socio-ecological systems.

This gap in comparative, configurational analysis is especially acute for rapidly urbanizing regions of the Global South, where natural endowments and governance capacities vary widely and where the stakes of unsustainable growth are exceptionally high. To address this, our study develops and validates a Qualitative Comparative Analysis (QCA) framework that systematically benchmarks 25 exemplar cities across six interdependent dimensions Ecological Urban Quality (ECOQ), Environmental & Geographic Factors (ENGE), Economic & Financial Conditions (ECOF), Political & Policy Factors (POP), Social & Cultural Dynamics (SOCC), and Technological Innovation (TECHI). By moving beyond isolated case narratives to identify robust "recipes" for ecological success and failure, this approach offers a more nuanced understanding of how multiple causal conditions coalesce in different urban contexts.

Filling this gap is critical not only for advancing urban theory but also for informing pragmatic policy design. City leaders and planners require decision-support tools that reveal which combinations of investments be they in green infrastructure, regulatory reform, social engagement, or clean technologies are most likely to generate resilience, equity, and ecological health. Our research therefore aims to (1) construct a composite ECOQ index and contextual condition scores for each city, (2) apply QCA to uncover the configuration patterns associated with positive and negative ecological outcomes, and (3) translate these findings into actionable guidance for urban policymaking. In doing so, we both contribute a novel methodological framework to the urban sustainability literature and provide practical pathways for cities pursuing transformative, context-sensitive ecological urbanism.

The remainder of this research paper is organized as follows. Section 2 reviews the extant literature on ecological urbanism, compact city paradigms, governance models, and QCA applications in urban studies. In Section 3, we develop our theoretical framework, defining the six key dimensions (ECOQ, ENGE, ECOF, POP, SOCC, TECHI) and detailing how they interact to shape ecological outcomes. Section 4 describes our methodology, including data collection for the 25 exemplar cities, the construction of composite indices, and the TOSMANA-based QCA procedures. Section 5 presents the results of our configurational analysis identifying the nine "recipes" for ecological success and the five for failure alongside illustrative case profiles. In Section 6, we discuss the theoretical and practical implications of our findings, offering guidance for policy design and highlighting avenues for future research. Finally, Section 7 concludes by summarizing our contributions and outlining how this QCA framework can support adaptive, context-sensitive ecological urbanism moving forward.

2. Literature Review

In the face of accelerating urban growth, environmental degradation, and the mounting pressures of climate change, the concept of ecological urbanism has emerged as a critical lens through which scholars and practitioners seek to reshape the future of cities. At its core, ecological urbanism calls for the seamless integration of natural systems ranging from biodiversity networks and green corridors to waterways into the very fabric of urban planning, design, and governance. This synthesis of twenty-five seminal works reveals a rich tapestry of theoretical foundations, conceptual models, practical strategies, and governance mechanisms that collectively chart a path toward cities that are resilient, equitable, and ecologically sound.

Early contributions laid the groundwork for ecological thinking by challenging modernist planning paradigms that had long prioritized rigid zoning and car-dependent infrastructures. Jacobs [2] famously advocated for the vibrancy born from diversity, mixed uses, and active public realms, while McHarg [1] pioneered ecological planning through the use of natural systems mapping to guide land-use decisions. Building on these insights, Forman [5] and Niemelä [6] conceptualized cities as complex socio-ecological systems, emphasizing how urban patterns and ecological processes interweave. Pickett et al. [7] along with Platt et al. [8] further underscored the importance of preserving habitat heterogeneity and connectivity within urban landscapes, advocating for green corridors and habitat restoration as essential policy instruments.

As theory advanced, several conceptual models crystallized, offering blueprints for sustainable urban futures. Timothy Beatley's Green Urbanism [3] distilled lessons from European cities that balance density with abundant green spaces and sustainable mobility. Register [9] proposed the "Ecocity" model, emphasizing low-impact development, renewable energy use, and walkable neighborhoods. Mostafavi and Doherty [10] framed "Ecological Urbanism" as an interdisciplinary nexus of architecture, landscape, and environmental science, while Newman and Jennings [4] presented "Sustainable Urban Ecosystems" as integrated systems where design and policy reinforce ecological functions. In response to looming energy and climate crises, Newman et al. [11] introduced the notion of "Resilient Cities," advocating for adaptive infrastructure networks and robust community participation.

Translating these models into practice has spurred the development of targeted policy instruments and planning methodologies. Farr [12] outlined form-based design approaches that embed green infrastructure and passive environmental strategies into urban layouts. Wheeler [13] and Wheeler and Beatley [14] compiled a comprehensive Urban Sustainability Framework, advocating for land-use planning that foregrounds environmental justice and participatory governance. Riddell

[15] emphasized zoning reforms, economic incentives, and performance standards as levers for balanced development. Recognizing the critical role of water, Perini and Sabbion [16] integrated river restoration with urban green space planning to enhance ecosystem services and community health. Meanwhile, scholars like Bibri et al. [17] and Dehghani et al. [18], and Salim and Lakshmi [19] turned attention to the Compact City paradigm, reviewing policies that promote density, mixed uses, and transit-oriented development as means of reducing emissions and conserving resources.

Central to the success of ecological policies are governance structures and stakeholder engagement. Joss [20] examined how institutional innovation and multi-level coordination enable sustainable urban experiments, while Dale and Onyx [21] highlighted the socio-spatial dynamics of sustainability, insisting on community-led planning and collaborative decision-making. Global perspectives compiled by Douglas et al. [22] and Marzluff et al. [23] demonstrated how diverse governance contexts shape ecological outcomes, and they underscored the importance of robust science–policy interfaces to translate ecological research into actionable regulations.

Despite substantial progress, contemporary challenges persist. Cohen [24] and Newman et al. [11] underscored the urgency of climate adaptation and decentralization to buffer cities against environmental shocks. The rise of data-driven "smart city" approaches implicit in Forman's spatial analyses and Dehghani's resilience reviews signals an emerging trend toward integrating geospatial and ecological indicators into policy evaluation. Moreover, the works of Wheeler and Beatley [14] and Dale and Onyx [21] call critical attention to issues of equity and environmental justice, warning that green policies must be designed to equitably distribute benefits across all socio-economic groups.

Looking ahead, there remains a pressing need for empirical studies that assess policy effectiveness in varied contexts, particularly in rapidly urbanizing regions of the Global South. Future research should explore mechanisms for integrating environmental, land use, and social policies across scales, conduct longitudinal analyses to validate theoretical models, and examine how participatory governance translates into concrete resilience and equity outcomes. By bridging these gaps, scholars and policymakers can better harness the multidisciplinary insights of ecological urbanism to drive meaningful, context-sensitive transformations in cities worldwide.

3. Theoretical Framework

Urban sustainability demands a multidimensional perspective that embraces not only ecological stewardship but also social equity, economic resilience, and robust governance. At the heart of our framework lies Ecological Urban Quality (ECOQ), a composite index that synthesizes five equally weighted pillars environmental sustainability, sustainable mobility, circular economy practices, climate resilience, and social welfare into a single 0–100 score. By normalizing key indicators such as air and water quality, green space preservation, per capita resource consumption, transit accessibility, waste diversion rates, hazard exposure, adaptation investments, housing affordability, and public health outcomes, ECOQ transcends narrow metrics to capture the intricate interplay between a city's natural systems and its inhabitants' well-being.

Yet no city exists in isolation. To understand why two municipalities with similar policy portfolios may exhibit disparate outcomes, we situate ECOQ within two contextual dimensions: Environmental & Geographic Factors (ENGE) and Economic & Financial Factors (ECOF). ENGE evaluates how a city's terrain, climate regime, ecosystem diversity, and exposure to floods, droughts, earthquakes, or coastal erosion shape both its challenges and its ecological assets. It further assesses the strength of pollution controls, the rigor of soil and water remediation programs, and investments in adaptive infrastructure from permeable pavements and green roofs to early-warning systems and managed-retreat plans. Meanwhile, ECOF gauges the fiscal foundations that enable or constrain sustainable urbanism. By examining per-capita GDP, income distribution, sectoral diversity, innovation clusters, financial instruments (such as green bonds and public-private partnerships), and a city's integration into regional and global trade networks, ECOF reveals whether economic vitality is being harnessed to finance low-carbon mobility, resilient supply chains, and circular-economy initiatives.

Beyond ecological conditions and economic strength, effective governance remains the linchpin of transformative action. Our third contextual axis, Political & Policy Factors (POP), captures the degree of regulatory rigor, institutional capacity, and cross-sector collaboration necessary to translate sustainability ambitions into binding policies and enduring practices. POP measures how local governments codify stringent emissions standards, embed global commitments such as the Paris Agreement and the UN Sustainable Development Goals into municipal master plans, and forge partnerships with private enterprises and civil society to scale renewable energy projects, green infrastructure, and smart city innovations. By scoring a city's public participation mechanisms and transparency in enforcement, POP ensures that environmental decisions are anchored in democratic accountability and social justice.

By weaving together ECOQ with ENGE, ECOF, and POP in a Qualitative Comparative Analysis (QCA), our framework offers a powerful diagnostic and strategic tool. Planners and policymakers can benchmark performance, diagnose contextual or institutional gaps, and identify which policy combinations green-space expansion plus transit investment, circular-economy incentives paired with resilience planning, or community-driven governance tied to innovative financing consistently yield the highest ecological and social dividends. In doing so, the model illuminates not only the cities that lead by example but also the pathways through which other urban centers might replicate their successes. Ultimately, this integrated approach charts a course toward urban futures that are carbon neutral, resource efficient, disaster resilient, economically vibrant, and deeply rooted in social equity thereby aligning the aspirations of humanity with the imperatives of the natural world on which it depends.

4. Research Method

Construction of the QCA Model (see [25, 26]) in order to assess the level of ecological urban development by assigning scores on a 100-point scale for the 25 ecological cities. The Ecological Urban Quality (ECOQ), measured by:

- Environmental Sustainability Index
- Sustainable Mobility & Transportation Index
- Circular Economy & Resource Efficiency Index
- Climate Resilience & Disaster Prevention Index
- Social Welfare & Quality of Life Index

Construction of the QCA model begins with a commitment to capturing the multifaceted nature of urban sustainability through a transparent, comparative framework. Twenty-five exemplar "ecological" cities are evaluated on a 0–100 scale, translating complex realities into actionable insights across three interrelated dimensions:

4.1. Ecological Urban Quality (ECOQ)

As a composite index, ECOQ synthesizes environmental stewardship, mobility systems, resource efficiency, climate resilience, and social welfare into a single performance score. By normalizing indicators air and water quality, green-space preservation, per capita resource consumption, transit accessibility, waste diversion, hazard exposure, adaptation infrastructure, housing affordability, and public health outcomes ECOQ reveals both ecological strengths and social inclusivity in urban settings.

4.2. Environmental & Geographic Factors (ENGE)

ENGE examines the physical context in which cities evolve. It assesses baseline environmental quality (air, water, soil), the effectiveness of pollution controls and remediation programs, and the diversity of local ecosystems (forests, wetlands, riparian corridors). It also measures hazard exposure floods, droughts, earthquakes, coastal erosion alongside investments in adaptive infrastructure such as green roofs, permeable pavements, early-warning systems, and managed-retreat plans. ENGE thereby contextualizes ECOQ, recognizing that a city's natural endowments and vulnerabilities shape the pathways to sustainability.

4.3. Economic & Financial Factors (ECOF)

ECOF captures the fiscal foundations of ecological urbanism. Key metrics include per capita GDP, income distribution equity, sectoral diversity, and the presence of innovation clusters. Financial infrastructure, banking systems, public–private partnership frameworks, green bond markets, and fiscal incentives are evaluated for their capacity to mobilize capital toward renewable energy, low-carbon transport, and resilient infrastructure. A city's integration into regional and global trade networks further amplifies access to cutting-edge environmental technologies and market opportunities.

Taken together, ECOQ, ENGE, and ECOF form the backbone of the QCA model. To this foundation we add a fourth axis:

4.4. Political & Policy Factors (POP)

POP distills regulatory commitment, global alignment, and cross-sector cooperation into a single governance score. It measures the rigor of environmental regulations, the integration of international agreements (e.g., the Paris Agreement, UN SDGs) into local planning, and the scope of public–private and community partnerships green bonds, innovation challenges, and joint ventures that translate policy into practice. By capturing political will and institutional capacity, POP reveals how governance can catalyze or stall the transition to ecological urbanism.

Beyond these core pillars, two additional dimensions address the social and technological drivers of sustainable cities:

4.5. Social & Cultural Factors (SOCC)

Sustainability is ultimately a human endeavor, shaped by values, behaviors, and modes of participation:

4.5.1. Environmental Literacy & Green Lifestyles

Measuring public awareness of ecological stress pollution, heat waves, extreme weather and the prevalence of practices such as recycling, energy conservation, and sustainable consumption indicates a community's readiness to embrace policy shifts. High SOCC scores reflect cities where green living is woven into daily routines, from transit choices to support for local organic markets.

4.5.2. Social Equity & Inclusive Development

True sustainability demands equitable distribution of benefits: clean water and sanitation, affordable housing near transit, and green-sector employment opportunities. Assessing these indicators ensures that urban growth reduces poverty and strengthens social cohesion, rather than exacerbating marginalization.

4.5.3. Community Engagement in Planning

Robust participatory processes workshops, digital platforms, citizen advisory councils enhance both the legitimacy and the effectiveness of development projects. By genuinely incorporating grassroots input, cities generate innovative, context-sensitive solutions and foster broad buy-in for environmental initiatives.

4.6. Technology & Innovation (TECHI)

Modern urbanism leverages technology to optimize resources, enhance resilience, and drive down emissions:

4.6.1. Smart City & Digital Platforms

Sensor networks and open-data ecosystems provide real-time insights into traffic flows, energy demand, and public-safety trends. Internet of Things applications can adjust streetlighting, predict infrastructure maintenance, and optimize waste-collection routes, while cloud-based dashboards empower transparent, data-driven governance.

4.6.2. Sustainable Mobility Solutions

The electrification of vehicle fleets supported by widespread charging infrastructure and battery-swapping hubs and the modernization of public transit are imperative for decarbonizing transport. Complementary measures, such as protected bike lanes, pedestrian plazas, and traffic-calming designs, promote active travel and healthier neighborhoods.

4.6.3. Green Building & Construction

Low-carbon materials (e.g., geopolymer concrete, sustainably harvested timber), high-performance insulation, and passive solar design can reduce building energy use. Modular and prefabricated construction minimizes waste, while green roofs and living walls manage stormwater and mitigate urban heat island effects.

4.6.4. Clean-Tech R&D & Smart Grids

Cutting-edge research in advanced photovoltaics, next-generation energy storage, and low-impact materials fuels large-scale renewable deployments solar farms, wind parks, biogas facilities that buffer cities against fossil-fuel volatility. Smart-grid management integrates these sources into a dynamic network, balancing supply and demand in real time, detecting faults early, and enabling two-way energy flows between utilities and consumers.

By systematically benchmarking each city across these four pillars core QCA dimensions (ECOQ, ENGE, ECOF, POP), social-cultural dynamics (SOCC), and technological innovation (TECHI) the model provides a rich diagnostic and strategic roadmap. Policymakers can pinpoint strengths to leverage, identify contextual or institutional gaps to address, and design bespoke policy mixes that steer their cities toward futures that are resilient, equitable, and deeply in tune with the natural systems upon which urban life depends.

Using the data obtained (see Annex 1 and Annex 2), we built the QCA model as follows:

Table 1.
Thresholds of QCA data analysis.

Conditional variables	Thresholds	Conditional variables	Thresholds
ECOQ	87.59	POP	89.28
ENGE	87.47	SOCC	89.12
ECOF	87.44	TECHI	90.43

Total configurations are 12; there are 9 configurations with a positive outcome [1], covering 20 cases. Also, there are 3 configurations with a negative outcome [0], covering 5 cases. Each configuration may correspond to one or more instances as identified by the software, rather than individual research cases. We will need to run the TOSMANA procedure (four steps) as follows: 1st Step: Minimal reduction without logical remainders for ecologically positive cities [1].
2nd Step: Minimal reduction without logical remainders for ecologically negative cities [0].
3rd Step: Minimal reduction with logical remainders for ecologically positive cities [1].
4th Step: Minimal reduction with logical remainders for ecologically negative cities [0].
We will see the accompanying table of configurations and case coverage as follows:

Table 2.
True Table of QCA analysis.

ID	ENGE	ECOF	POP	SOCC	TECHI	ECOCQ
Copenhagen, Stockholm, Vancouver, Zurich, Oslo, Amsterdam, Berlin, Helsinki, Munich	1	1	1	1	1	1
Reykjavik	1	1	1	1	0	1
Singapore, Seoul	0	1	1	0	1	1
Portland, Ljubljana	1	0	0	1	0	1
Freiburg	1	0	1	1	1	1
Curitiba	1	0	0	0	0	1
Melbourne	0	1	1	1	0	1
Barcelona	0	1	0	0	1	0
Hamburg	0	1	1	0	0	1
Masdar City, Bogotá, Quito	0	0	0	0	0	0
San Francisco, Paris	0	1	1	1	1	1
Sydney	0	1	0	0	0	0

5. Results

A. First Procedure: Minimal Reduction without Logical Remainders for Ecologically Positive Cities (Outcome = 1)

First, we run the first procedure to perform a minimal reduction of the configurations yielding a positive ecological outcome [1], without including any logical remainders. The following formulae are obtained:

ECOF * POP * SOCC +	ENGE * ECOF * POP +	ENGE * POP * SOCC * TECHI +	ENGE * ecof * pop * techi
(Copenhagen,Stockholm,Vancouver,Zurich, Oslo,Amsterdam,Berlin,Helsinki,Munich+Reykjavik+Melbourne+San Francisco,Paris)	(Singapore,Seoul +Melbourne+Hamburg+San Francisco,Paris)	(Copenhagen,Stockholm,Vancouver, Zurich,Oslo,Amsterdam,Berlin,Helsinki,Munich+Freiburg)	(Portland,Ljubljana+Curitiba)

It can be re-written as follows:
[ECOF * POP * SOCC] → positive ecological cities [Outcome = 1] (1)
[ENGE * POP * SOCC * TECHI] → positive ecological cities [Outcome =1] (2)
[enge * ECOF * POP]→ positive ecological cities [Outcome =1] (3)
[ENGE * ecof * pop * techy]→ positive ecological cities [Outcome =1] (4)

Configuration (1) can be understood to mean that the configuration of three conditions ECOF * POP * SOCC: Economic & financial factors (ECOF), population factors (POP), and social & cultural factors (SOCC)—is sufficient to produce an ecologically positive city [Outcome = 1].

Configuration (2) shows a combination of ENGE * POP * SOCC * TECHI that environmental & geographic factors (ENGE), population factors (POP), social & cultural factors (SOCC), and technological & innovation factors (TECHI) together yield an ecologically positive city [Outcome = 1].

Configuration (3) indicates that economic & financial factors (ECOF) along with population factors (POP) and political & policy factors (ENGE) suffice to produce an ecologically positive city [Outcome = 1], even if environmental & geographic factors are lacking.

Configuration (4) suggests that environmental & geographic factors (ENGE) can generate an ecologically positive city [Outcome = 1] even in the absence of economic & financial factors, political & policy factors, and technological & innovation factors.

However, these combinations lack detail and therefore require further investigation using the procedure that includes logical remainders for ecologically positive cities [Outcome = 1].

B. Second Procedure: Minimal Reduction without Logical Remainders for Ecologically Negative Cities (Without logical remainder, Outcome = 0)

enge * ECOF * pop * socc +	enge * pop * socc * techi
(Barcelona+Sydney)	(Masdar City,Bogot,Quito+Sydney)

[enge * ECOF * pop * socc] → negative ecological cities [Outcome = 0] (5)
[enge * pop * socc * techy] → negative ecological cities [Outcome = 0] (6)
(5) The combination of environmental & geographic factors, political & policy factors, and social & cultural factors leads to an ecologically negative city [Outcome = 0], even under positive economic & financial conditions.
(6) The combination of the above factors plus technological & innovation factors, leads to an ecologically negative city [Outcome = 0].

C. Third Procedure: Minimal Reduction with Logical Remainders for “Positive Ecological City” (Outcome = 1)

Continuing the TOSMANA run with a logical remainder for the "Positive Ecological City" condition (With Logical Remainder, Outcome = 1), the results are shown below:

ENGE +	POP
(Copenhagen,Stockholm,Vancouver,Zurich,Oslo,Amsterdam,Berlin,Helsinki,Munich+Reykjavik+Portland,Ljubljana+Freiburg+Curitiba)	(Copenhagen,Stockholm,Vancouver,Zurich,Oslo,Amsterdam,Berlin,Helsinki,Munich+Reykjavik+Singapore,Seoul+Freiburg+Melbourne+Hamburg+San Francisco,Paris)

We can restate it as follows:
Condition ENGE → Positive Ecological City [Outcome = 1] (7)
Condition POP → Positive Ecological City [Outcome = 1] (8)

This highlights the independent, critical roles of Environmental & Geographic Factors (ENGE) and Political & Policy Factors (POP) in producing a Positive Ecological City (Outcome = 1), as shown in (7) and (8).

D. Fourth Procedure: Minimal Reduction with Logical Remainders for Ecologically Negative Cities (Without logical remainder, Outcome = 0)

Continue running the TOSMANA procedure with logical remainder (With logical remainder, Outcome = 0), yielding the following results:

enge * pop
(Barcelona+Masdar City,Bogot,Quito+Sydney)

We can restate this as:
[ENGE * POP] → Negative Ecological City [Outcome = 0] (9)

This indicates that only the combined presence of Environmental & Geographic Factors (ENGE) and Political & Policy Factors (POP) leads to a negative ecological-quality outcome (Outcome = 0). Notably, there is no symmetric individual effect of either condition when producing the "Negative Ecological City" result.

5.1. Synthesis and Policy Discussions

From these results, we derive Equations 1 through 9.

Environmental & Geographic Factors (ENGE) and Political & Policy Factors (POP) play key roles in producing a Positive Ecological City [Outcome = 1].

We can therefore classify the cities into two groups as follows:

Group 1: ENGE	(Copenhagen,Stockholm,Vancouver,Zurich,Oslo, Amsterdam,Berlin,Helsinki,Munich+Reykjavik+Portland,Ljubljana+Freiburg+Curitiba)
Group 2: POP	(Copenhagen,Stockholm,Vancouver,Zurich,Oslo,Amsterdam,Berlin,Helsinki,Munich+Reykjavik+Singapore ,Seoul+Freiburg+Melbourne+Hamburg+San Francisco,Paris)

We will compare and identify the cities that appear in Group 1 but not in Group 2, and vice versa.

Cities in Group 1 but not in Group 2:

- Portland
- Ljubljana
- Curitiba

Cities in Group 2 but not in Group 1:

- Singapore
- Seoul
- Melbourne
- Hamburg
- San Francisco
- Paris

A case-by-case review shows that the three cities unique to Group 1 share naturally high environmental quality:

- Portland:
    - *Environmental Quality:* Excellent air quality thanks to abundant urban greenery and "green" practices, though summer forest fires can cause temporary declines.
    - *Pollution Control & Protection:* Strong focus on public transit, green space expansion, and renewable energy, particularly wind power.
- Ljubljana:
    - *Environmental Quality:* Clean air and water resulting from robust environmental protection policies.
    - *Pollution Control & Protection:* Strict car restrictions, extensive public transportation, and comprehensive water-source protection have earned it the title "Green Capital of Europe."
- Curitiba:
    - *Environmental Quality:* Air quality can suffer from urbanization and traffic, but the city has implemented effective pollution-reduction measures.

- *Pollution Control & Protection:* Renowned for its advanced public transit system, widespread recycling programs, and preservation of natural areas.

Thus,

- Portland maintains strong environmental safeguards and stable air and water quality, though it remains vulnerable to forest fires and seismic events.
- Ljubljana has achieved significant successes in environmental protection and sustainable development, especially in mobility and resource management.
- Curitiba is distinguished by its innovative public transit and conservation efforts, but still faces climate-change–related and resource-management challenges.

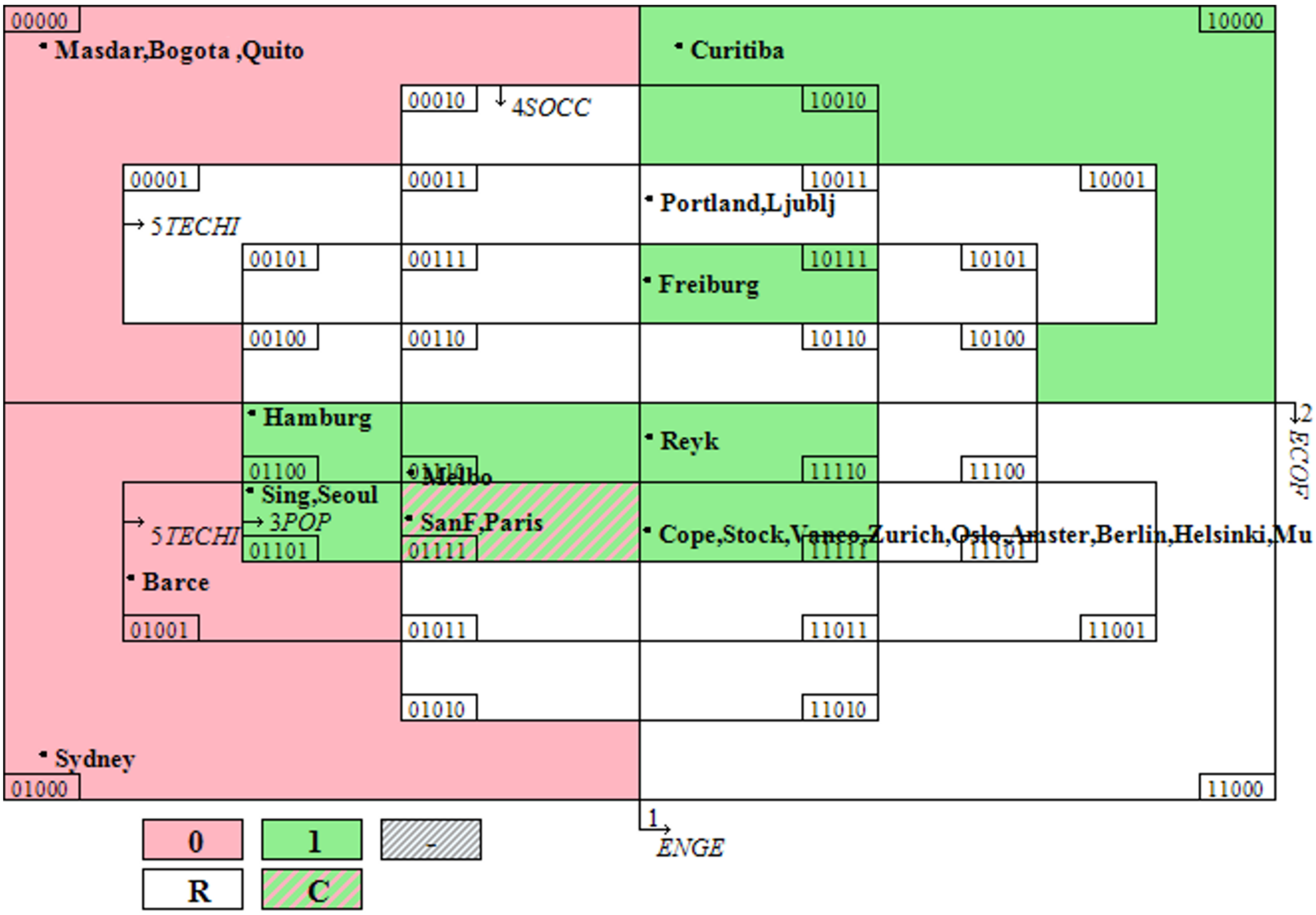

Figure 1.
TOSMANA results represented graphically.

Research on the six cities, Singapore, Seoul, Melbourne, Hamburg, San Francisco, and Paris reveals that each exhibits a strong commitment to sustainable development, active participation in international agreements, and effective public-private collaboration to advance green and lasting initiatives.

Government commitment and regulatory rigor are foundational to the success of urban sustainability initiatives, as evidenced by leading cities around the world. In Singapore, the national government has embedded environmental stewardship at the heart of its development agenda. The Green Plan 2030, a comprehensive roadmap published in 2021, sets ambitious targets for renewable energy uptake, improvements in energy efficiency, and deep cuts in carbon emissions. To ensure that these goals translate into real-world outcomes, Singapore enforces strict environmental regulations from stringent vehicle emissions standards to mandatory green building certifications that safeguard both natural resources and residents' quality of life.

In Seoul, municipal authorities have likewise made high-level policy pledges to confront air pollution, reduce waste, and expand urban greenery. The Seoul Green Plan articulates a vision of circular waste management, extensive public transit expansion, and new park developments on underutilized land. These measures not only reduce the city's ecological footprint but also foster healthier, more livable neighborhoods. By coupling regulatory mandates such as emissions limits for industry and construction with incentives for rooftop gardens and urban agriculture, Seoul seeks to weave sustainability into everyday life.

Melbourne's government has taken a similarly proactive stance by embedding climate action into its long-range planning framework. Its climate strategy emphasizes renewable energy generation, water conservation, and biodiversity protection, all underpinned by rigorous environmental regulations. Through financial incentives, such as rebates for buildings that exceed energy efficiency benchmarks and grants for community-led sustainability projects, Melbourne encourages both developers and citizens to contribute to the city's low carbon transition.

In Northern Europe, Hamburg's Climate Plan exemplifies aggressive regulatory ambition. The city has legislated binding targets to reduce greenhouse gas emissions by 55 percent by 2030, compared with 1990 levels, and to achieve carbon neutrality by 2050. Hamburg's laws mandate green roofs on new construction, tax incentives for solar installations, and stringent performance standards for heating and cooling systems. Together, these regulations safeguard critical ecosystems while driving the city toward a sustainable energy future.

On the West Coast of the United States, San Francisco's municipal administration has championed sustainability through a suite of regulatory measures designed to slash emissions, minimize waste, and speed the adoption of clean technologies. The city's green building code requires that all new large developments meet rigorous energy and water efficiency standards, and its Zero Waste by 2030 initiative has propelled investments in composting, recycling, and repurposing facilities. Complementary air quality ordinances such as restrictions on diesel-powered construction equipment underscore San Francisco's holistic approach to urban environmental health.

Finally, Paris has leveraged its influential role on the global stage to enact robust climate policies at home. The Paris Climate Plan outlines binding objectives for reducing carbon emissions by 40 percent by 2030 (relative to 1990), expanding pedestrian-only zones, and improving public transit affordability and accessibility. To meet these aims, the city enforces emissions-based restrictions in its central districts, subsidizes electric vehicle charging infrastructure, and invests heavily in bus and metro upgrades. By coupling regulatory stringency with concerted public transit enhancements, Paris demonstrates how policy and planning can converge to yield cleaner air and a more sustainable urban milieu.

Cities around the world have reinforced their sustainability agendas by embedding international commitments into local action plans, leveraging global frameworks to accelerate climate progress and ecological stewardship. Singapore, for instance, aligns its national targets with the Paris Agreement and the United Nations' Sustainable Development Goals (SDGs), translating these high-level pledges into concrete milestones for renewable energy deployment and carbon emissions cuts. By ratifying these accords, Singapore not only signals its dedication on the world stage but also frames its domestic Green Plan 2030 within an integrated network of global objectives, ensuring coherence between local policies and collective climate ambitions.

Similarly, Seoul has woven international sustainability agreements into the fabric of its urban strategy. As a signatory to the Paris Agreement and an active participant in SDG initiatives, the city has set explicit goals for reducing greenhouse gas emissions, scaling up renewable energy capacity, and expanding sustainable mobility. These global commitments inform Seoul's investments in electric vehicle infrastructure, its retrofitting of public buildings for energy efficiency, and its support for low-carbon research and innovation, demonstrating how multilateral frameworks can drive city-level action.

In Melbourne, the municipal government has likewise pledged adherence to international targets, particularly for decarbonization and biodiversity conservation. By publicly endorsing the Paris Agreement and integrating SDG metrics into its annual sustainability reports, Melbourne ensures that its climate adaptation plans and urban greening programs meet both local needs and global benchmarks. This alignment enables the city to attract international funding and partnerships for reforestation projects, habitat restoration, and citizen-science initiatives that bolster biodiversity resilience.

Hamburg's engagement with global environmental accords is equally robust. Beyond formal membership in the Paris Agreement, the city consults United Nations sustainability guidelines when setting its own emissions-reduction trajectories and renewable energy mandates. These international benchmarks guide Hamburg's climate planning, from its ambitious target of cutting greenhouse gas emissions by 55 percent by 2030 to its support for cross-border renewable energy grids. By synchronizing local policy with multilateral goals, Hamburg fosters regulatory certainty and international collaboration in the renewable energy sector.

On the west coast of the United States, San Francisco exemplifies how a city can champion international agreements through domestic policy. By endorsing the Paris Agreement, even when federal alignment was uncertain the city reaffirmed its commitment to deep carbon cuts and a clean-energy transition. San Francisco's Climate Action Strategy references SDG indicators to track progress in areas like air-quality improvement, waste diversion, and renewable-energy adoption, illustrating how global frameworks can inform municipal program design and performance measurement.

Finally, Paris itself stands as a global beacon of climate leadership by virtue of hosting the landmark 2015 UN climate conference. The city has translated its historical role into contemporary ambition, adopting the Paris Agreement's goals as minimum standards for its own policies. With binding targets to reduce carbon emissions by 40 percent by 2030 and sweeping plans to expand renewable-energy capacity, Paris ensures that its local roadmap mirrors—and often exceeds—the requirements set forth in international sustainability agreements. Through these integrated commitments, each city demonstrates that global accords are most potent when they are paired with clear, enforceable targets and actionable programs at the municipal level.

Public–private partnerships (PPPs) have become indispensable catalysts for urban sustainability, enabling cities to leverage the agility and innovation of the private sector alongside public oversight and financing. In Singapore, the government has cultivated a fertile PPP ecosystem in which leading technology and energy companies collaborate on large-scale green projects. From solar farm rollouts to the deployment of smart grid technologies, these alliances ensure that cutting-edge innovations are both piloted and scaled under supportive regulatory frameworks. By sharing risks and aligning profit motives with sustainability goals, Singapore's PPPs have accelerated its transition toward a low-carbon economy.

Likewise, Seoul's municipal administration relies on robust partnerships with both domestic conglomerates and international firms to bring its environmental ambitions to life. Major transit-oriented developments, such as electric-bus fleets and metro-station retrofits, are executed in concert with private contractors who supply the vehicles, energy-management systems, and maintenance services. In the renewable-energy sector, business consortiums co-finance solar and wind installations, while private developers construct green-certified buildings under incentive schemes that reward resource-efficient design.

In Melbourne, PPPs underpin many of the city's flagship sustainability initiatives. The government provides seed funding and regulatory clearances, and private investors contribute technical expertise and capital for projects ranging from large-scale battery storage facilities to hydrogen fuel cell research. Collaborative ventures in public transit—such as the design and operation of new tram extensions demonstrate how shared governance models can deliver public good infrastructure that meets strict environmental benchmarks without overburdening taxpayers.

Hamburg's approach to PPPs emphasizes the rapid deployment of renewable energy and energy efficiency measures. Municipal authorities issue tenders for energy performance contracts in which private energy service companies retrofit public buildings with state-of-the-art insulation, heat recovery systems, and rooftop photovoltaics. These performance-based agreements guarantee cost savings that are shared between the city and the contractor, effectively aligning financial returns with carbon reduction targets.

On the U.S. west coast, San Francisco has harnessed PPPs to tackle waste reduction and clean-energy rollout simultaneously. Private firms spearhead cutting-edge recycling and composting facilities under long-term contracts, while renewable-energy developers partner with the city to build offshore wind and rooftop-solar projects. Through joint ventures, the city and its private partners co-invest in microgrid pilots that enhance community resilience and demonstrate new business models for distributed energy resources.

Finally, in Paris, public–private collaboration is central to expanding sustainable urban mobility and improving air quality. The city's transit authority teams up with technology startups to deploy electric bike sharing and next-generation e-bus fleets, while utility companies co-finance district heating networks that run on waste heat. International organizations, such as the European Investment Bank, often join these partnerships as co-lenders, amplifying the scale and impact of local projects. By embedding PPPs within its broader climate strategy, Paris ensures that private capital and expertise are consistently marshaled to meet its ambitious decarbonization goals.

In summary, these six global cities illustrate how layered governance, international alignment, and cross-sector cooperation combine to advance urban sustainability. Singapore exemplifies a holistic approach, marrying robust regulatory frameworks and public–private partnerships with concrete Paris Agreement and SDG commitments to drive renewable energy and emissions reduction targets. Seoul mirrors this integration by embedding sustainability pledges into transit and clean energy investments co-developed with the private sector. Melbourne reinforces its climate ambitions through long-term climate strategies, adherence to global accords, and joint ventures that deliver innovative environmental solutions. Hamburg's aggressive Climate Plan is matched by performance-based contracts with private energy services companies, accelerating its shift to renewables. San Francisco demonstrates tight coordination between municipal mandates and private enterprises, setting a benchmark in waste minimization, microgrid pilots, and clean energy deployment. Finally, Paris leverages its leadership in international climate diplomacy to underpin rigorous local policies coupled with dynamic public–private collaborations that have positioned it at the forefront of carbon reduction and air quality improvement efforts. Together, these cases affirm that cities achieve transformative sustainability when governance, global commitments, and private sector engagement are strategically aligned. Analysis of the three cases with strong Environmental & Geographic Factors (ENGE) and the six cases with strong Political & Policy Factors (POP) demonstrates that these two sets of conditions operate relatively independently. Moreover, Equations 1, 2, 3, 7, and 8 indicate that political and policy factors play a crucial role in producing a Positive Ecological City (Outcome = 1).
We can therefore accept the following nine combinations as valid:

ENGE{0}ECOF{0}POP{1}SOCC{0}TECHI{0}
ENGE{0}ECOF{0}POP{1}SOCC{0}TECHI{1}
ENGE{0}ECOF{0}POP{1}SOCC{1}TECHI{0}
ENGE{0}ECOF{0}POP{1}SOCC{1}TECHI{1}
ENGE{1}ECOF{0}POP{1}SOCC{0}TECHI{0}
ENGE{1}ECOF{0}POP{1}SOCC{0}TECHI{1}
ENGE{1}ECOF{0}POP{1}SOCC{1}TECHI{0}
ENGE{1}ECOF{1}POP{1}SOCC{0}TECHI{0}
ENGE{1}ECOF{1}POP{1}SOCC{0}TECHI{1}

ENGE{0}ECOF{0}POP{0}SOCC{0}TECHI{1} +
ENGE{0}ECOF{0}POP{0}SOCC{1}TECHI{0} +
ENGE{0}ECOF{0}POP{0}SOCC{1}TECHI{1} +
ENGE{0}ECOF{1}POP{0}SOCC{1}TECHI{0} +
ENGE{0}ECOF{1}POP{0}SOCC{1}TECHI{1}

Considering Equation 9:
[ENGE * POP] → Negative Ecological City [Outcome = 0**]**
this demonstrates that the joint absence of both Environmental & Geographic Factors (ENGE = 0) and Political & Policy Factors (POP = 0) leads to a negative ecological outcome. Accordingly, we can state:
When ENGE = 0 and POP = 0, the result is a Negative Ecological City [Outcome = 0].

We therefore accept the following five configurations as valid:

Table 3.
Summary Comparison of Environmental & Geographic Factors for Selected Cities with Low Ecological Urban Quality

Criteria	Bogotá	Quito
Air – Water – Soil	High air pollution, water and soil quality are poor	Relatively stable air quality; water meets safety standards
Pollution Level & Protection Measures	Implementing BRT system; increasing urban greenery	Gradually strengthening anti-pollution policies
Location – Topography – Landscape	Highland plateau surrounded by the Andes	Situated in a volcanic valley at high altitude
Biodiversity	High featuring forests, mountains, and rivers	Highly home to multiple forest and mountain ecosystems
Natural Disasters & Resilience	Risks of flooding and landslides, uneven urban development	High earthquake risk; slow pace of infrastructure upgrades
Climate & Climate Change	Heavy rainfall leads to frequent urban flooding.	Highland climate is particularly vulnerable to climate shifts
Resource & Ecological Management	Natural resources are heavily exploited, though management is improving	Biodiversity protection policies remain limited

From Table 3, examining Bogotá and Quito, while rich in natural assets and biodiversity, they face notable environmental and geographic challenges that contribute to their low ecological urban quality (ECOQ). Bogotá suffers from high air pollution and poor water and soil quality, largely due to vehicle emissions and unregulated development. Quito maintains relatively better air and water standards, though infrastructure weaknesses persist. Bogotá has implemented a BRT system and urban greening efforts, while Quito is gradually tightening anti-pollution policies. Both cities face gaps between planning and enforcement. Bogotá's plateau traps pollutants but allows room for expansion. Quito's volcanic valley offers rich biodiversity but increases vulnerability to landslides and seismic activity. Both cities are biodiversity hotspots, with forests, rivers, and mountain ecosystems. However, unchecked urban sprawl threatens critical habitats. Bogotá faces flooding and landslides, worsened by informal development. Quito is at high earthquake risk and is slow to upgrade infrastructure. Bogotá struggles with flooding from heavy rains. Quito's highland climate makes it vulnerable to climate variability and ecological stress. Bogotá is improving after decades of overexploitation, while Quito's biodiversity policies remain underfunded and inconsistently applied. Both cities must strengthen urban planning, enforce environmental regulations, and scale up nature-based solutions to improve ecological resilience and sustainability.

Table 4.
Comparison Table of Political & Policy Factors (POP) for Cities with Low Ecological Urban Quality

POP Criteria	Bogotá	Quito
Government Commitment & Regulations	Moderate – Commitment is growing, but enforcement capacity remains limited.	Fair – City government is attentive but faces budgetary and organizational challenges.
International Agreements & Sustainability Goals	Committed to SDGs and C40 membership, but implementation is constrained by resource shortages.	Participates in SDGs and has a climate action plan, yet execution has been slow.
Public–Private Collaboration	Moderate – Some BRT and green-urban projects involve private partners.	Fair – PPPs exist but are uneven, with insufficient long-term incentives.

From Table 4, the political and policy frameworks in Bogotá and Quito show varying degrees of commitment to ecological sustainability, but both cities face implementation and coordination hurdles. Bogotá shows moderate political will, with improving commitment but limited enforcement due to institutional constraints. Quito's local government is engaged but struggles with financial and administrative capacity to fully implement sustainable policies. Both cities align with global sustainability agendas—Bogotá is a C40 member and supports SDGs, while Quito has a climate action plan and SDG participation. However, in both cases, limited resources hinder effective execution and long-term impact. Public–private partnerships (PPPs) are present but underdeveloped in both cities. Bogotá includes private actors in projects like BRT and green urbanism, yet coordination is often fragmented. Quito has PPPs in place, but these lack consistency and long-term incentives to drive sustained ecological investment. While Bogotá and Quito are politically aligned with sustainability goals, deeper institutional reforms, stronger regulatory enforcement, and more robust public–private collaboration are essential to raise their ecological urban quality.

6. Conclusion

This study advances a comprehensive QCA framework to assess ecological urban quality across 25 exemplar cities by integrating six interdependent dimensions: environmental integrity, governance capacity, economic resilience, sociocultural engagement, technological innovation, and geographic context. Our analysis reveals that positive ecological outcomes emerge not from any single factor but from specific configurations most notably the interplay between Environmental and Geographic Factors (ENGE) and Political and Policy Factors (POP).

Empirical results demonstrate that cities with strong natural endowments such as Copenhagen, Stockholm, and Vancouver leverage high biodiversity, effective pollution controls, and adaptive infrastructure to achieve superior ecological performance. Equally, cities like Paris, Seoul, and Singapore illustrate how rigorous policy frameworks, robust institutional capacity, and active participation in international agreements can compensate for more modest environmental advantages. The identification of nine distinct "recipes" for ecological success underscores the strategic value of combining governance excellence with social, economic, and technological enablers. Conversely, five configurations linked to underperformance highlight the risks posed by simultaneous deficiencies in environmental stewardship and policy support.

Case studies of Bogotá and Quito further underscore that, in contexts where natural assets are present but institutional or financial capacities falter, progress stalls. These examples illuminate the critical need for strengthened regulatory enforcement, institutional reform, and resource mobilization to translate ecological potential into concrete improvements particularly in rapidly urbanizing regions of the Global South.

In summary, our QCA-based approach offers both a nuanced theoretical contribution clarifying how multiple causal conditions coalesce to shape urban ecological trajectories and a practical decision-support tool. By allowing urban planners and policymakers to benchmark performance, diagnose contextual gaps, and tailor interventions, this framework paves the way for more resilient, equitable, and ecologically sound urban futures.

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Annex 1.
Evaluation of Ecological Urban Quality for 25 Prominent Cities Based on 5 Equally Weighted Criteria (Each Criterion Scored from 1 to 100).

No.	City	Environmental Sustainability Index	Sustainable Mobility & Transportation Index	Circular Economy & Resource Efficiency Index	Climate Change Resilience & Disaster Prevention Index	Social Welfare & Quality of Life Index	Ecological Urban Quality (Average Score) - coded: ECOQ
1	Copenhagen	96	97	94	93	95	95
2	Stockholm	95	96	93	92	94	94
3	Reykjavik	93	90	92	90	91	91
4	Singapore	90	92	88	89	93	90
5	Vancouver	92	90	89	88	92	90
6	Zurich	93	91	90	90	94	92
7	Portland, Oregon	90	91	88	87	90	89
8	Freiburg	94	93	92	90	93	92
9	Curitiba	88	90	87	85	88	88
10	Oslo	92	93	90	91	92	92
11	Melbourne	89	88	87	86	90	88
12	Barcelona	88	89	87	85	88	87
13	Ljubljana	90	91	89	90	92	90
14	Amsterdam	91	92	90	89	91	91
15	Hamburg	89	88	87	87	90	88
16	Masdar City	85	80	82	84	80	82
17	Seoul	88	90	87	86	89	88
18	Bogotá	80	82	78	80	82	80
19	Berlin	90	91	89	88	90	90
20	Helsinki	91	92	90	91	93	91
21	San Francisco	89	88	87	85	88	87
22	Munich	92	93	90	91	92	92
23	Sydney	88	87	86	85	89	87
24	Quito	82	80	80	78	82	80
25	Paris	90	92	89	88	91	90

Annex 2.
Summary of Evaluation Scores on a 100-Point Scale.

ID	Ecological Urban Quality (ECOQ)	Environmental & Geographical Factors (coded: ENGE)	Economic & Financial Factors (coded: ECOF)	Political & Policy Factors (coded: POP)	Social & Cultural Factors (coded: SOCC)	Technological & Innovation Factors (coded: TECHI)
Copenhagen	95	93	92	95	95	94
Stockholm	94	93	93	94	94	95
Reykjavik	91	95	88	92	92	90
Singapore	90	80	98	93	88	98
Vancouver	90	97	90	90	92	92
Zurich	92	92	97	92	93	94
Portland, Oregon	89	90	87	88	90	89
Freiburg	92	92	85	95	94	93
Curitiba	88	88	80	85	85	87
Oslo	92	93	92	93	92	92
Melbourne	88	87	90	90	90	90
Barcelona	87	86	88	88	88	91
Ljubljana	90	90	82	87	90	88
Amsterdam	91	88	90	93	91	93
Hamburg	88	87	90	90	88	90
Masdar City	82	75	70	80	75	80
Seoul	88	85	95	90	87	95
Bogotá	80	80	80	85	80	80
Berlin	90	88	90	92	92	92
Helsinki	91	90	88	93	93	93
San Francisco	87	84	95	90	91	97

Munich	92	90	93	92	92	94
Sydney	87	87	90	88	88	90
Quito	80	75	75	80	78	75
Paris	90	86	94	90	90	92