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The Decalogue of Urban Mobility: From Theoretical Framework to a Practical Index (UMDI)

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Abstract

Urban decarbonization is essential to mitigate the global climate emergency. While some cities face systemic socio-environmental challenges rooted in fossil-fuel-dependent mobility, some others are rapidly developing infrastructure with poor or without planning frameworks. To address the gap between fossil-fuel-dependent urban mobility and unplanned infrastructure development, and to improve urban mobility in all types of cities, this paper introduces the Urban Mobility Decalogue, a theoretical framework structured around ten core dimensions: safety, equity, justice, sustainability, health, cleanliness, efficiency, effectiveness, commitment, and civic consciousness. To operationalize this framework, we develop the Urban Mobility Decalogue Index (UMDI). The UMDI evaluates each principle using three universally accessible sub-indicators, creating a robust set of Key Performance Indicators (KPIs). Metrics are normalized through a standardized scoring system and integrated mathematically into a composite score. Additionally, a four-tier certification system classifies performance into color-coded bands (labels A, B, C, and D). Empirical exercises across three contrasting archetypes (Copenhagen, Barcelona, and Houston) show the index's ability to benchmark diverse mobility models and socio-environmental realities. Ultimately, the UMDI offers a scalable, data-driven tool for policymakers to evaluate, visualize, and accelerate urban transitions.

Keywords: urban mobility; decalogue; quantification; index; KPI; scoring

1. Introduction

1.1. Motivation

Urban decarbonization is a fundamental imperative to address the global climate emergency. Given that 75% of the European population resides in urban areas, cities account for approximately 25% of total greenhouse gas emissions, with nearly 60% of this share directly attributed to mobility. In developed countries, urban mobility planning is institutionalized through strategic instruments such as Sustainable Urban Mobility Plans (SUMPs), which are periodically updated. Conversely, in other regions, particularly in the Global South, urban infrastructure is still developing, often lacking coherent planning frameworks; indeed, it is estimated that approximately 60% of urban infrastructure related to mobility is currently under construction. In Western cities, the degradation of air quality, along with systemic physical and mental health issues, stems directly from fossil-fuel-dependent mobility systems, which have historically shaped urban morphology and design. Consequently, regardless of their current level of planning, cities worldwide fundamentally require a robust conceptual framework to define and implement mobility models aligned with contemporary socio-environmental realities.

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1.2. The Existing Urban Mobility Plans and Their Limitations

The rapid acceleration of global urbanization in the context of the climate emergency has placed urban mobility at the core of sustainability and governance agendas in cities. Historically, transport planning was based on a conventional engineering paradigm focused on maximizing automobile throughput, design speed, and road capacity expansion, treating mobility as a derived demand to be minimized through the reduction in travel time costs [1]. This traditional approach has generated significant environmental and social externalities, manifested in issues such as chronic congestion, air pollution and its associated health problems, greenhouse gas emissions that worsen the climate crisis, spatial fragmentation, the loss of public space for citizens, and distributional inequity. Over the past two decades, both academia and public policy have evolved toward multidimensional evaluation frameworks. However, existing diagnostic tools and instruments exhibit methodological and interpretative limitations that justify the formulation of a new framework. Currently, various urban mobility approaches and plans coexist to guide cities toward a sustainable mobility transition. Within the European institutional framework, Sustainable Urban Mobility Plans (SUMPs) promote the integration of active modes and public transit under standardized frameworks such as the Sustainable Urban Mobility Indicators (SUMIs), centered primarily on climate crisis adaptation, pollution reduction, and air quality improvement. Parallelly, international frameworks such as the ASI (Avoid–Shift–Improve) scheme approach mobility by structuring demand reduction, modal shift, and technological efficiency. Likewise, global synthetic indices (e.g., WBCSD Sustainable Mobility Indicators or Deloitte's City Mobility Index) and academic models based on multi-criteria decision methods (such as AHP or TOPSIS) have proliferated. Despite their valuable contributions, critical studies highlight that these frameworks suffer from recurring shortcomings, such as a lack of normative calibration, as they often rely on sample-dependent relative statistical transformations rather than discretizing variables through objective thresholds grounded in international regulatory standards (WHO, EEA, ITDP, and Vision Zero). They evaluate deeply heterogeneous metropolitan realities using universal static templates, ignoring the fact that traffic dynamics and modal efficiency are intrinsically tied to urban scale, density, and physical spatial form [2,3]. Furthermore, they frequently omit the social and behavioral dimension, reducing the road network to a logistical movement corridor and ignoring that streets and transit hubs act as architectures that condition social interaction, civic trust, and spatial justice (e.g., [4]).

In addition, existing mobility evaluation models often omit the socio-spatial and behavioral dimensions inherent to urban mobility infrastructure. Transport networks do not function simply as neutral logistical channels for physical displacement; rather, streets and public transport spaces constitute behavioral architectures that actively dictate patterns of social exposure, public space vitality, and community trust [4]. Physical urban landscapes and transit networks govern how human social interactions unfold across time and space, acting as key determinants of civic engagement and urban livability. When transport assessment tools reduce mobility to mere flow efficiency or fleet electrification metrics, they ignore the fundamental principles of mobility justice, which emphasize how infrastructure design can either remedy or perpetuate spatial segregation, structural immobility, and marginalization. Addressing these scientific and practical limitations requires a context-sensitive, multidimensional evaluation tool, such as the Urban Mobility Diagnostic Index (UMDI), that bridges the conceptual principles of sustainability with the application of operational diagnostics, providing a scientifically grounded decision-support framework capable of diagnosing structural deficits and guiding targeted policy interventions across globally diverse urban systems.

1.3. The Urban Mobility Decalogue

To address these limitations, a new framework structured as a decalogue is presented here, articulated across 10 dimensions and 30 key indicators that quantify them. This framework offers a balanced and operationally viable diagnostic tool that transcends the fragmentation of traditional plans by balancing environmental sustainability, the social and equity dimension, and system efficiency and governance. By grounding the discretization of its indicators in standardized international thresholds (on an ordinal scale from 0 to 4), subjecting its aggregation to global sensitivity analyses, and interpreting its results according to local urban morphology, this decalogue not only fills a methodological gap in the literature but also provides public managers with a reliable, transferable instrument for strategic decision-making and diagnostics that extend beyond purely efficiency and environmental criteria. According to this framework, contemporary urban mobility must be safe, equitable, just, sustainable, healthy, clean, efficient, effective, committed, and civically conscious.

Despite the widespread adoption of instruments like SUMPs, existing urban mobility assessment frameworks suffer from critical structural limitations that impede effective decarbonization. Traditional evaluation tools remain overwhelmingly car-centric, relying on engineering metrics such as traffic volume, road capacity, and vehicle throughput that treat congestion as a flow problem rather than a spatial-justice deficit. Furthermore, contemporary multi-criteria evaluation methods are frequently fragmented, hyper-specialized, or excessively reliant on proprietary data, rendering them opaque and inaccessible for comparative benchmarking across diverse geographic contexts. Crucially, conventional frameworks fail to capture the complex, multidimensional interdependencies between public health, spatial equity, environmental justice, and active transit efficiency. They often allow municipalities to mask systemic infrastructural failures behind isolated technological milestones, such as fleet electrification, without achieving actual reductions in vehicle miles traveled. To bridge this analytical gap, a unified, open-access diagnostic framework, the Urban Mobility Decalogue and the associated index (UMDI), is required to provide a holistic, anti-greenwashing metric that evaluates urban movement through a comprehensive social and environmental lens.

To fully grasp the transformative potential of sustainable transport, urban mobility must be conceptualized not merely as a set of isolated transit networks but as a dynamic subsystem embedded within a complex urban system. Urban mobility is continuously shaped by non-linear interactions among spatial form, physical infrastructure, socioeconomic organization, environmental pressures, and human behavior [5]. Recognizing this systemic complexity is essential for understanding how local interventions ripple across urban scales, where a change in street design simultaneously impacts air quality, economic access, active health, and social cohesion. The ten dimensions of the Urban Mobility Decalogue are explicitly structured to capture these multi-faceted feedback loops, providing a coherent diagnostic architecture that bridges micro-level behavioral shifts with macro-level sustainability transitions. By situating mobility within this complex system paradigm, the framework aligns with the broader global literature on urban transformations, offering cities a holistic tool to navigate decarbonization, spatial justice, and urban resilience in an increasingly urbanized world.

2. Materials and Methods

2.1. The Dimensions of the Urban Mobility Decalogue

The concept of constructing a guiding framework for urban mobility in the form of a decalogue emerges from a dual perspective at the intersection of executive public policy and academic research. Grounded in hands-on experience across local governance and academia, the ten dimensions proposed here reflect recurring structural deficits observed

in real-world municipal planning across environmental, social, and operational governance domains. Structuring this framework as a decalogue provides a practical, memorable, and operationally efficient roadmap for those tasked with implementation, primarily municipal technicians, urban planners, and policymakers.

The identification, selection, and organization of these ten core points followed a systematic process designed to bridge practical governance needs with scientific rigor. First, fundamental themes were identified by mapping chronic municipal planning failures, specifically those routinely sidelined in conventional plans, such as socio-spatial equity. Second, dimensions were selected to serve as direct policy levers while remaining mutually exclusive and offering comprehensive coverage across three fundamental pillars: environmental sustainability, social equity, and system efficiency. Sequentially, these dimensions form a balanced diagnostic matrix wherein environmental imperatives establish boundary conditions, social dimensions guarantee spatial equity, and governance dimensions provide the operational mechanisms for execution.

Scientifically, the ten dimensions are fully aligned with established international regulatory paradigms and policy directives, including the EU Mission for Climate-Neutral and Smart Cities, global energy transition roadmaps, World Health Organization (WHO) air quality guidelines, European Union environmental directives, and several of the UN Sustainable Development Goals. Following the formal definition of these dimensions, their corresponding Key Performance Indicators (KPIs) were selected directly from the mainstream reference literature and peer-reviewed sources in urban management to ensure scientific rigor, empirical comparability, and operational transferability across heterogeneous urban systems.

The subsections that follow detail and scientifically substantiate the necessity of each dimension within the Urban Mobility Decalogue.

2.1.1. Safe Mobility

Road safety constitutes the fundamental cornerstone of any sustainable mobility system. According to the World Health Organization [6], road traffic collisions cause approximately 1.19 million deaths globally each year, remaining the leading cause of mortality among children and young adults aged 5 to 29. Within the European Union, despite rigorous regulatory advancements, 39% of all traffic fatalities in 2023 occurred in urban environments [7]. This evidence underscores that safety cannot be treated as a mere byproduct of urban planning; rather, it must be established as an explicit, cross-cutting objective.

The "Safe System Approach" paradigm, championed by the European Transport Safety Council [8], posits that no death or serious injury is acceptable within the transportation network. This framework operates on the principle that humans are inherently prone to error, and therefore infrastructure, vehicle design, and traffic regulations must be engineered to minimize the consequences of these mistakes. In this context, speed management emerges as a critical determinant. Empirical research by the World Health Organization [9] indicates that the probability of death for a pedestrian struck by a vehicle at 50 km/h is approximately 80%, whereas this risk drops sharply to 10% when the speed is reduced to 30 km/h. Cities that have pioneered the *30 km/h city model* have documented reductions of 25–40% in severe and fatal accidents within less than three years from implementation [10]. Furthermore, the promotion of active mobility, particularly cycling, serves as an effective and sustainable safety strategy. An extensive body of literature demonstrates that increasing the modal share of cycling yields a systemic reduction in overall accident rates. This phenomenon, widely conceptualized as "safety in numbers" [11,12], demonstrates that as the volume of cyclists grows, the individual risk of injury decreases due to heightened driver awareness, visibility, and behavioral adaptation. Additionally, research by Pucher et al. [13] highlights

that cities with high cycling rates, such as Copenhagen and Amsterdam, not only exhibit exceptionally low traffic mortality rates but also experience compounded benefits in public health, air quality, and noise pollution mitigation.

Conversely, entrenched car dependency in urban centers generates pervasive risks associated with excessive speeds, congestion, and the monopolization of shared space. Private automobiles occupy more than 70% of urban public road space [14] despite accounting for less than 30% of total trips in many European cities. This spatial disproportion exacerbates systemic insecurity and severely constrains democratic modal coexistence. Ultimately, Gehl [15] pointed out that a safe city is one that invites people to walk and stay, not just to pass through. Achieving safe mobility thus requires a structural reconfiguration of public space that prioritizes vulnerable road users (VRUs), decelerates motorized traffic, and incentivizes active transit. This comprehensive strategy does not merely save lives; it enhances collective well-being and urban vitality, establishing safety as a core instrument of social justice and urban sustainability.

2.1.2. Equitable Mobility

Equitable mobility is an essential component of an inclusive and sustainable urban system. Beyond merely moving people, transportation serves as a powerful catalyst for social justice, as it dictates who can access education, employment, healthcare, and community life. According to Lucas [16], transport inequality leads to social inequalities of opportunity; hence, transport planning must systematically ensure that all individuals, regardless of gender, age, income level, or physical ability, can travel safely, affordably, and with dignity. Here, equitable mobility refers to whether the transportation system provides equal opportunity, universal physical access, and financial affordability for all individuals, regardless of gender, age, income, or physical ability.

Empirical data show that mobility inequalities directly impact social cohesion. According to Venter [17], low-income households and residents of urban peripheries tend to allocate a disproportionately higher share of their time and income to transportation, while paradoxically having access to fewer sustainable mobility options. Furthermore, vulnerable groups, including women, the elderly, children, and persons with disabilities, experience the greatest physical and social barriers during their daily journeys [18]. In this regard, equitable mobility is not merely a technical matter of infrastructure but a core issue of governance and participatory planning.

Transport policies centered on equity seek to redistribute public space and resources to favor active and collective modes. The ITF [19] highlights that up to 80% of public road space in many European cities is currently dedicated to private vehicles, despite accounting for only 30–40% of daily trips. This spatial disparity generates a form of "mobility injustice" [20,21] that penalizes the most sustainable and accessible modes of transit. Reversing this trend requires bold policies for the equitable reallocation of public space, robust investment in high-quality public transit, and secure cycling networks that seamlessly connect peripheral neighborhoods with socioeconomic opportunities. Moreover, equitable mobility inherently demands a gender-responsive and intersectional perspective. Research by De Madariaga [22] demonstrates that women tend to make shorter, more complex, multimodal trips tied to caregiving responsibilities, a structural pattern conceptualized as the "mobility of care." This evidence underscores the urgent need to plan mobility systems centered around everyday lived experiences rather than strictly economic or productive logics. Universal accessibility, perceived personal safety, and proximity to services are, therefore, fundamental pillars of a truly equitable mobility system. A city characterized by equitable mobility is one that does not discriminate on socioeconomic or physical grounds; it actively redistributes time, space, and resources, framing mobility as a fundamental civic

right. As Sheller [21] summarizes, "mobility justice is justice in motion", without which true urban equity cannot exist.

2.1.3. Just Mobility

Just mobility operates on the foundational principle that the right to movement is an essential civic and human right. It extends beyond merely securing the freedom of movement to ensuring that this freedom does not generate structural inequalities or disproportionate socio-spatial impacts on other communities or territories. Sheller [21] argues that mobility justice is an overarching framework for thinking about how all forms of movement and stillness are deeply unequal and highly politicized in contemporary societies. This perspective places transport planning within the broader matrix of social and environmental justice, highlighting the critical interdependencies between transportation, energy distribution, territorial planning, and public well-being. Just mobility operates at the macro-societal and institutional level, examining the distributive justice of environmental externalities and the procedural justice of decision-making.

According to the European Environment Agency [23], the transport sector accounts for roughly 25% of total greenhouse gas emissions in the European Union, with road transport alone generating 71% of this share. The negative externalities of this system, such as localized air pollution, acoustic stress, traffic collisions, and the monopolization of public space, disproportionately impact vulnerable socioeconomic demographics who are often least responsible for generating them. This environmental inequality reveals that current mobility paradigms are inherently unjust, as the social and ecological costs are systematically externalized onto those who derive the least utility from the system [24].

The distributive justice in transport posits that transportation policies must structurally prioritize accessibility for underserved populations rather than focusing primarily on traffic throughput or aggregate economic efficiency. This requires reorienting public capital investments toward high-capacity public transit, active mobility infrastructure, and proximity-based planning, thereby ensuring that all citizens can fully participate in the socioeconomic life of the city.

In parallel, regarding procedural justice within urban planning, Pereira et al. [25] highlight the critical importance of governance: specifically, *who* is involved in the decision-making process and *whose* voices shape mobility policies. Democratic public participation, particularly involving traditionally marginalized demographics such as women, youth, immigrant communities, and persons with disabilities, is indispensable for developing institutional frameworks that are both legitimate and responsive to diverse urban lived experiences.

On the global scale, the principles of mobility justice align directly with the United Nations Sustainable Development Goals (SDGs 10 and 11), which advocate for reduced inequalities and the creation of inclusive, safe, resilient, and sustainable cities. Guaranteeing just mobility ultimately means equitably distributing the spatial and temporal benefits of movement (access, travel time savings, and opportunities) while comprehensively mitigating its social and environmental burdens.

In synthesis, just mobility represents a profound paradigm shift: transitioning from viewing transport merely as a logistical tool for moving people and goods to understanding it as an instrument for social and environmental equity. According to Pereira et al. [25], the right to mobility cannot be decoupled from the right to the city and the right to a healthy environment. Only when all individuals can move freely, without exacerbating or enduring structural inequalities, can a truly just mobility system be achieved.

2.1.4. Sustainable Mobility

Sustainable mobility is a defining concept for 21st-century urban development, seeking to guarantee the right to movement without compromising the resources of future generations. According to the European Commission [26], a sustainable mobility system meets basic access needs while reducing negative externalities. This model requires integrating the three core pillars of sustainability: environmental, economic, and social. Here, sustainable mobility refers to the long-term structural alignment of transport with planetary boundaries, measuring mainly greenhouse gas (GHG) reduction. The transport sector is a primary driver of the climate emergency, accounting for one-quarter of total GHG emissions in the European Union, with 71% originating from road transport [23]. Entrenched private vehicle dependency has caused urban CO_2 emissions to remain stagnant despite technological advancements [27]. Beyond CO_2, internal combustion engines release hazardous localized pollutants like NO_2 and $PM_{2.5}$, linked to over 300,000 premature deaths annually in Europe [28], while traffic noise exposes 20% of the population to dangerous acoustic stress, according to the World Health Organization [29].

Spatially, automobiles monopolize over 70% of public road space despite accounting for less than 40% of daily trips [15,21]. Rebalancing the urban right-of-way by prioritizing active mobility and mass transit is both an environmental and social imperative. While vehicle electrification is necessary, it is insufficient without reducing total motorized travel demand; sustainability requires a profound transformation of behavioral paradigms [30]. The automobile-centric model imposes massive structural costs. Transport externalities account for roughly 3% of the EU's GDP, equivalent to €400 billion annually, driven by pollution, noise, and collisions [31]. Individually, commuters waste 60 to 120 h per year in congestion. Conversely, public transit is highly spatially efficient, transporting up to 20 times more passengers per unit of space than private cars [32]. Furthermore, active mobility yields a high return on investment; every euro invested in cycling infrastructure generates €3 to €6 in social and health benefits [33]. Fair road pricing mechanisms (e.g., Low-Emission Zones) can reduce traffic volumes by 15% to 25% based on the "polluter pays" principle [34].

Sustainable mobility is deeply connected to social justice, as the burdens of transport are misallocated [25]. Vulnerable socioeconomic groups bear a disproportionate share of traffic harms while experiencing systemic barriers to affordable transit. The absence of reliable public transit serves as a primary vector for European social exclusion [16].

From a public health perspective, according to the World Health Organization, active travel mitigates cardiovascular diseases and obesity, while reclaiming public space fosters social cohesion [35]. Ultimately, sustainable mobility acts as an essential catalyst for the United Nations Sustainable Development Goals (SDGs 3, 10, 11, and 13), reinforcing the premise that "there is no sustainable city without a sustainable mobility system" (UN-Habitat, [36]). According to Banister [30], true sustainability requires giving the reduction in motorized trips the same priority as reducing emissions.

2.1.5. Healthy Mobility

Healthy mobility places human health, encompassing physical, mental, and social well-being, at the core of urban transportation policies. According to the World Health Organization [6], health is not merely the absence of disease. Applied to transport, this paradigm demands a structural shift where active mobility, specifically walking and cycling, functions as a powerful tool for disease prevention and health promotion, aligning logistical efficiency with clinical benefits.

The contemporary motorized transport model exerts a profound burden on population health. Traffic-related atmospheric pollution is epidemiologically linked to over

300,000 premature deaths annually in the European Union, driven by chronic exposure to $PM_{2.5}$ and NO_2 [13], while acoustic stress incurs systemic healthcare costs of €20 billion annually. Furthermore, automobile dependency exacerbates physical inactivity; the World Health Organization [6,37] estimates that one in four adults fails to meet physical activity thresholds, increasing risks for cardiovascular diseases, diabetes, and obesity.

Conversely, active transportation serves as preventative medicine. Epidemiological research lead by Celis-Morales [38] involving over 250,000 participants demonstrated that active bicycle commuters experience a 41% reduction in all-cause mortality and a 45% lower risk of cardiovascular disease. Risk-benefit analyses conclude that the health benefits of transitioning to cycling outweigh the potential risks of traffic accidents or pollution exposure by a factor of up to nine [39].

Engaging in regular active commuting enhances cardiorespiratory fitness and mitigates chronic non-communicable diseases [40]. Mentally, active mobility is strongly associated with decreased indices of stress, anxiety, and depression, while significantly boosting emotional well-being and life satisfaction through heightened environmental connectivity [41]. Societally, traffic-calming interventions and pedestrian presence encourage spontaneous social interactions and increase neighborhood safety [42,43]. Walkable environments also promote the inclusion of vulnerable demographic groups, such as children and the elderly, cultivating more egalitarian cities.

To make active transport viable, the WHO's "Health in All Policies" [44] advocates for integrating health metrics into transport planning through universal 30 km/h speed limits, segregated cycling networks, and safe pedestrian pathways. Municipalities implementing these strategies demonstrate high-yield outcomes. In Copenhagen, where 49% of commuting trips are made by bicycle, public health data reveal an annual saving of over €200 million in healthcare expenditures [45]. Economically, every euro invested in cycling infrastructure generates €3 to €5 in net social returns due to reduced healthcare burdens [13,46].

Finally, healthy mobility is intrinsically bound to environmental justice. Low-income neighborhoods frequently experience disproportionate exposure to traffic corridors and pollution, according to the European Environmental Agency [47]. Reallocating public right-of-way toward active infrastructure effectively redistributes health benefits, mitigating systemic exposure disparities and uplifting collective public health.

2.1.6. Clean Mobility

Clean mobility focuses on the immediate physical cleanliness and localized environmental impacts of vehicles and infrastructure. It focusses on tailpipe pollutants (NOx, SOx, and PM) and non-exhaust microparticle deposition from brake and tire wear. According to the United Nations Framework Convention on Climate Change and the European Green Deal, clean mobility constitutes an indispensable pillar of the contemporary urban ecological transition, critical to fulfilling the targets of the Paris Agreement [48,49]. The transport sector remains the primary producer of greenhouse gas (GHG) emissions within the European Union, accounting for approximately 25% of the aggregate total; crucially, unlike other sectors, its emissions have failed to decrease since 1990 [47]. Within this sector, road transport is responsible for 71% of total emissions, with private passenger automobiles acting as the predominant contributor.

According to the European Environmental Agency, surface motorized traffic represents a primary vector of ambient atmospheric pollution. Nitrogen oxides (NOx) and fine particulate matter ($PM_{2.5}$) generated by internal combustion engines account for more than 300,000 premature deaths annually across Europe [50], prompting the World Health Organization [51] to institute more stringent air quality guidelines. Furthermore, road transport releases over 600 million tons of CO_2 equivalent annually in the EU [23], a

figure intricately linked to sprawling urban morphologies and an inefficient average vehicle occupancy rate of fewer than 1.5 persons per trip.

Achieving clean mobility requires a deep socio-technical energy transition structured around the established Avoid–Shift–Improve (ASI) framework [52]. Avoid involves mitigating unnecessary motorized travel demand via compact, mixed-use urban planning and proximity-based design. Shift means transferring the remaining transport demands toward highly sustainable, shared, and active modes like mass transit and cycling. Improve involves maximizing energy efficiency and zero-emission propulsion. Within this pathway, vehicle electrification stands as a central strategy, capable of reducing urban transport emissions by up to 60% by 2035, provided that charging grids are powered entirely by renewable energy [53].

The Low-Emission Zones (LEZs) have emerged as highly effective regulatory mechanisms, deployed by more than 320 European cities [7]. Impact assessments document substantial pollutant reductions, showing drops of 20–30% in ambient NO_2 concentrations and up to 15% in $PM_{2.5}$ levels [54]. To ensure social equity, these regulations must be bundled with affordable mobility alternatives, subsidized public transit, and targeted cycling incentives.

Economically, the green mobility sector could generate over one million new jobs across the EU by 2030 [55]. Furthermore, mitigating air pollution yields immediate public health cost savings; every euro invested in clean air interventions generates health-related economic returns between 4 and 30 times greater than the initial expenditure [29]. From a social standpoint, clean cities advance environmental equity by reducing unequal exposure to toxic pollutants historically observed between low- and high-income neighborhoods [21,24].

Clean mobility serves as the primary mechanism for achieving carbon-neutral urban ecosystems, aligning with the European Commission's (2021) strategy to reduce urban transport emissions by 90% by 2050 [55]. Creutzig et al. synthesize in their study that clean mobility is not achieved simply by electrifying private cars but by electrifying society toward a new urban culture of responsible movement [52].

2.1.7. Efficient Mobility

Efficient mobility seeks to maximize the socioeconomic yields of transport systems while drastically minimizing their associated environmental and energetic overheads. Within a contemporary landscape defined by the climate crisis and infrastructure saturation, optimizing efficiency is vital to guarantee that transit networks remain sustainable, accessible, and resilient. Mobility-related efficiency measures resource productivity, i.e., how well spatial, temporal and energy inputs are converted into movement. It can be operationalized across four complementary dimensions: energetic, temporal, spatial, and economic.

According to the International Energy Agency [53], the transportation sector accounts for approximately 30% of the aggregate final energy consumption within the European Union, with 96% sustained by fossil fuels. The private passenger vehicle remains the least efficient transit mode; internal combustion engines convert less than 25% of their consumed energy into useful kinetic propulsion, whereas electric rail networks exceed 70% operational efficiency. While replacing combustion fleets with electric vehicles mitigates operational emissions by up to 70%, this reduction is strictly contingent upon charging infrastructures being integrated into renewable grids [47].

Spatially, private vehicles are critically inefficient. An individual automobile occupies an average of 10 m^2 of rights-of-way when in motion and up to 25 m^2 when parked, despite frequently operating with a single occupant [15,56]. In contrast, a standard public bus accommodates up to 50 times more passengers within an equivalent surface area, and dedicated cycling infrastructure can process 5 times more users per hour, per meter of

right-of-way [19]. Allocating over 60% of urban public space to private motorized vehicles imposes a severe opportunity cost on civic life, reducing green infrastructure and stifling local economies [57].

Urban traffic congestion serves as a primary source of systemic temporal friction. According to Yang et al. [58], European drivers lose an average of 120 h annually to traffic delays, inflicting an economic deficit exceeding €110 billion per year across the EU. Reversing this trend requires coupling demand-management strategies with Intelligent Transport Systems (ITSs) and big data analytics for real-time route optimization [56]. Crucially, temporal efficiency reflects the societal productivity and quality of the time spent in transit; as Banister notes [30], it does not consist of moving faster but rather of moving better.

From an economic perspective, negative transport externalities within the EU amount to €820 billion annually, equivalent to roughly 5.5% of European GDP, with road transport generating 70% of this drain [59]. Conversely, every euro invested in pedestrian and cycling networks yields between €3 and €5 in societal value, driven by healthcare savings, localized emission abatement, and commercial revitalization [13,46].

Newman et al. [60] argue that an efficient city is one that structurally minimizes the necessity of long-distance motorized travel, rather than one which facilitates unconstrained, limitless movement. True efficiency is unlocked when mobility is leveraged as a vital mechanism to foster collective sustainability and human well-being.

2.1.8. Effective Mobility

Effective mobility focuses on maximizing the holistic societal returns of transit networks, rather than merely reducing travel times or absolute spatial distances. It measures goal fulfillment and functional utility, i.e., whether the transportation system successfully fulfills its societal function. This paradigm integrates land-use planning, technological interventions, demand-management frameworks, and multimodal coordination to construct a highly functional, accessible infrastructure. According to the European Commission [56], an effective mobility network transports a greater volume of passengers using fewer resource inputs, while concurrently guaranteeing safety, sustainability, and social inclusion. System effectiveness is evaluated by its real-world impact on urban quality of life and the systemic equity of access to public services and socioeconomic opportunities.

An effective transportation ecosystem must be coordinated, predictable, and reliable. Operational frictions, such as congestion, prolonged wait times, and poor multimodal synchronization, constitute primary vectors of urban psychological stress and macroeconomic productivity loss [61]. Operational effectiveness is fundamentally contingent upon substantive intermodality: the seamless physical and digital integration of mass transit, cycling infrastructure, pedestrian networks, and shared micro-mobility. Multimodal integration enhances the aggregate structural capacity of the transit network, mitigating the necessity for high-cost physical investments while significantly improving spatial accessibility [62,63]. Furthermore, effective mobility must guarantee that all civic strata enjoy equitable access to metropolitan services. The efficacy of a network depends not on absolute velocity but on its structural capacity to connect individuals across diverse socioeconomic gradients to employment, education, and healthcare [16]. Mass transit coverage must be geometrically comprehensive and chronologically synchronized, with a particular emphasis on peripheral zones where lower-income populations are disproportionately concentrated, thereby reducing social exclusion [25].

Suboptimal transit networks incur severe hidden external costs; urban traffic congestion inflicts an annual deficit exceeding €110 billion across European cities, but sustained investments in robust public transit can reduce these costs by up to 40% [31]. Synthesizing

sustainable infrastructure design, premium mass transit, and active mobility is critical to achieving equilibrium between operational throughput and environmental goals [13,30].

Emerging digital technologies facilitate real-time, data-driven supply-side optimization. The utilization of big data analytics, integrated Mobility-as-a-Service (MaaS) applications, and vehicle-sharing platforms optimizes resource allocation, minimizes empty vehicle trips, and enables evidence-based decision-making [56]. Finally, long-term efficacy is structurally dependent on the institutional alignment of transport planning and urban morphology. Compact, mixed-use urban developments with high-density transit nodes reduce unnecessary motorized travel demand and enhance trip productivity [61]. Effective transport is not characterized by mere speed but by systemic functionality. It moves people safely and sustainably while generating net positive societal spillovers [30].

2.1.9. Committed Mobility

Committed mobility dictates that urban transportation networks must actively interface with global sustainability and health agendas, fulfilling institutional obligations established by international treaties. This paradigm represents a profound social and political responsibility that structurally ties local municipal decisions to multi-scalar global targets, including the Paris Agreement [48], the United Nations Sustainable Development Goals (SDGs 3, 11, and 13), and the European Green Deal [49].

The transportation sector remains a primary driver of anthropogenic greenhouse gas (GHG) emissions. According to the European Environment Agency [23], transport accounts for approximately 25% of total CO_2 emissions within the European Union. Globally, the Intergovernmental Panel on Climate Change [64] estimates that transport is responsible for 14% of global emissions, a figure that continues to climb in the absence of structural interventions.

Committed mobility directly aligns local urban policy with the decarbonization path mandated by the Paris Agreement through major structural shifts: substituting internal combustion engines with zero-emission electric vehicles, scaling up public transit and active mobility networks to dismantle private automobile dependency, and executing proximity-oriented land-use planning to compress daily trip distances [30,52].

A committed framework demands rigorous regulatory policies to curb hazardous atmospheric pollutants like $PM_{2.5}$ and NO_2. The World Health Organization [51] estimates that ambient urban air pollution accounts for over 4 million premature deaths annually worldwide, concentrated within dense traffic corridors. Metropolises that have deployed aggressive interventions, such as Low-Emission Zones (LEZs) and congestion pricing, have documented reductions of up to 30% in ambient NO_2 concentrations, alongside substantial improvements in respiratory and cardiovascular health [65,66].

To realize global macro-targets, such as the European Green Deal's "Fit for 55" package, which mandates a net 55% reduction in EU emissions by 2030 [56], municipal governments must translate international pledges into granular local interventions. This requires combining innovative technologies, infrastructure incentives, and participatory governance to deliver fully electrified public transit fleets, extensive cycling greenways, and continuous civic education [13,52].

Committed mobility operates simultaneously as an ethical imperative. The environmental externalities generated by transport are inherently misallocated: socioeconomically marginalized demographics, who exhibit lower vehicle ownership rates, are disproportionately exposed to toxic vehicular emissions and acoustic pollution [21,24]. Enacting a committed mobility strategy means correcting this imbalance, establishing distributional environmental justice, and ensuring equitable access to clean, safe, and subsidized transit assets while defending environmental health benchmarks against political rollbacks.

2.1.10. Civic and Social Mobility

Urban mobility operates as far more than a transactional mechanism for circulating commodities and bodies; it constitutes a primary vector for social cohesion and the collaborative production of urban space. The civic and social mobility paradigm recognizes that rights-of-way and transit corridors double as critical arenas for democratic convergence, interpersonal exchange, and civic participation. As Gehl [15] posits, streets and public spaces function as foundational socio-spatial platforms where the specific modes of navigation determine perceived public safety, structural social inclusion, and aggregate urban vitality.

Daily transit patterns, whether enacted via pedestrian navigation, cycling, or mass transport, generate continuous affordances for spontaneous communication and a shared sense of place. Active mobility increases casual encounters among neighbors, which actively reduces alienation and enhances localized perceptions of public safety [13]. Conversely, an infrastructure that disproportionately prioritizes private motorized vehicles inevitably exacerbates structural socioeconomic stratification and spatial segregation [16]. Universal accessibility and the unconditional inclusion of historically marginalized populations are non-negotiable requirements to optimize collective community integration.

Reallocating the public realm by reducing the spatial footprint of private automobiles to prioritize pedestrian networks, cycling ways, and traffic-calmed zones directly improves prosocial interactions. Reconfiguring high-speed arterials into low-velocity, high-density pedestrian corridors drastically increases local social encounters and lowers crime anxieties [15].

Simultaneously, mass public transportation stands as a crucial structural anchor for sociodemographic convergence. The shared utilization of municipal transit brings together citizens across diverse sociodemographic and cultural gradients, fostering values of social tolerance, mutual respect, and heightened civic consciousness [67]. Furthermore, emerging asset-sharing models, such as municipal bike-sharing, expand this collaborative ethos, incentivizing public cooperation and shared resource stewardship [68].

Built environments designed to prioritize human-scale interaction encourage routine physical activity, lower chronic cortisol exposure, and enhance mental health outcomes [69]. Mitigating systemic acoustic pollution and vehicle volumes removes communication barriers and unlocks new possibilities for stable community life [50]. Achieving this requires sustained investments in civic literacy and mobility education to nurture defensive road manners and asset-sharing cooperation [13].

Furthermore, the design of urban mobility systems plays a decisive role in shaping human sociability and collective behavior within the public realm. Beyond serving as logistical conduits for spatial displacement, streets and transit networks act as primary behavioral architectures that either foster or constrain social interaction, trust, and civic vitality. As highlighted in the recent behavioral urbanism literature (e.g., [4]), spatial configurations, pedestrian accessibility, and the velocity of urban flows directly alter micro-level social dynamics, influencing lingering time, casual face-to-face encounters, and community cohesion. By prioritizing human-scale streetscapes, stationary comfort, and traffic-calmed public spaces, the UMDI framework evaluates how cities leverage mobility infrastructure not merely to move bodies efficiently but to cultivate positive social behaviors, enhance democratic public life, and strengthen the civic fabric of urban communities.

2.2. Quantification of the Urban Mobility Decalogue

To operationalize the theoretical principles of the decalogue discussed previously, an integrated Urban Mobility Decalogue assessment matrix is proposed. This framework converts systemic definitions into verifiable, quantitative, and qualitative metropolitan metrics.

Now that the relevance of the ten dimensions that constitute the Urban Mobility Decalogue has been demonstrated, an Urban Mobility Decalogue Index (UMDI) is built which relies on a multi-criteria diagnostic architecture structured across ten core dimensions, each operationalized through three Key Performance Indicators (KPIs) to establish a balanced set of thirty metrics. To eliminate structural double-counting during aggregation, indicator selection follows a Single-Primary-Assignment Protocol governed by a Direct Unit of Measurement Rule, assigning each metric to a single mutually exclusive dimension based strictly on its direct physical unit and primary policy target rather than secondary co-benefits. Continuous observed indicator values are discretized onto a standardized 5-point ordinal scale (from 0 to 4) via a piecewise step function using absolute normative threshold bounds derived from international reference frameworks (e.g., WHO air quality guidelines, ITDP accessibility standards, EEA acoustic limits, and Vision Zero safety tiers). The baseline composite index is evaluated as an equally weighted linear additive sum, which serves as a non-arbitrary, neutral reference baseline prior to local preference alignment and acts as an institutional safeguard against selective compensation greenwashing.

For each of the principles of the decalogue, Table 1 shows three different measurables KPI findable in sectorial and global urban plans and studies. The selection of the 30 Key Performance Indicators (KPIs) governing the UMD architecture was executed through a targeted synthesis of the international urban transport benchmarking literature (mainly the European Environmental Agency, the Organization for Economic Co-operation and Development, the International Transport Forum, and UN-Habitat), structured to ensure a balanced, robust, and globally operational framework. Indicators were evaluated and selected based on four explicit criteria: first, a conceptual alignment with the core theoretical mandate of the respective decalogue principle; second, data accessibility and openness, requiring indicators to rely on standardized, non-proprietary datasets or open GIS infrastructure to enable global replicability without high data-acquisition barriers; third, orthogonality, minimizing multi-collinearity between KPIs within the same dimension; and fourth, policy sensitivity, ensuring that each metric directly reflects municipal policy interventions rather than unchangeable geographic constraints. By restricting the framework to three highly representative, non-redundant indicators per dimension, the quantification of the UMD avoids metric inflation and excessive data-collection burdens while providing a concise, multidimensional diagnostic baseline for comparative urban analysis.

Each of the ten principles within the decalogue is evaluated by three distinct Key Performance Indicators (KPIs), which are scored on a scale ranging from 0 to 4. The thresholds for assigning these scores are grounded in international engineering and planning standards, such as the WHO Air Quality Guidelines for environmental indicators and the Vision Zero Academy criteria for safety metrics. Table 2 operationalizes each individual KPI, detailing the specific metric, unit, or qualitative checklist required to allocate scores from 0 (critical/non-compliant) to 4 (benchmark/ideal state).

Table 1. The Urban Mobility Decalogue assessment matrix. The first column corresponds to each of the ten points of the decalogue. The second column synthetizes the main operation goal. The third column defines three KPI for each of the decalogue points.

Decalogue Principle	Operational Policy Goal	KPI
1. Safety	To systematically eliminate traffic-related deaths and serious injuries through a proactive infrastructure model.	**KPI 1.1:** Number of traffic fatality and serious injury rate per 100.000 inhabitants per year. **KPI 1.2:** % of the municipal street network restricted to ≤30 km/h. **KPI 1.3:** Percentage of active traffic-calming structural upgrades at crossings.

Table 1. *Cont.*

Decalogue Principle	Operational Policy Goal	KPI
2. Equitable	To guarantee spatial accessibility for all sociodemographic groups, removing physical and economic barriers.	**KPI 2.1:** % of public transit fleet and stations featuring 100% universal accessibility. **KPI 2.2:** Transit Affordability Index: Cost of a monthly unlimited transit pass as a % of minimum wage. **KPI 2.3:** % of low-income homes within 400 m of a high-capacity transit node.
3. Just	To ensure fair spatial and environmental redistribution of public rights-of-way among different urban modes.	**KPI 3.1:** Right-of-Way Reallocation Ratio: % of total public street area allocated to active travel/transit vs. private cars space. **KPI 3.2:** Noise/pollution exposure gap between poor/rich areas. **KPI 3.3:** Pedestrian/Cycling Infrastructure Equity: Bike/pedestrian infrastructure density ratio (periphery vs. center).
4. Sustainable	To decouple urban transit from environmental degradation by prioritizing low-carbon travel.	**KPI 4.1:** Modal Split Shift: Percentage of total daily trips made via active mobility and public transit vs. private motor vehicles. **KPI 4.2:** Annual per capita transportation CO_2 equivalent emission reduction trend. **KPI 4.3:** Aggregate private Vehicle Kilometers Traveled (VKT) variation.
5. Healthy	To foster active travel routines that mitigate urban environmental stressors and enhance physical and mental well-being.	**KPI 5.1:** Active commuting rate (walking + cycling) daily modal share (in %). **KPI 5.2:** % of population exposed to traffic noise above WHO guidelines (>53 dB Lden). **KPI 5.3:** Linear meters of public parks and nature-based infrastructure integrated into active travel corridors per 1000 residents.
6. Clean	To transition toward zero-emission urban areas by eradicating localized tailpipe pollutants.	**KPI 6.1:** Number of days per year exceeding WHO guidelines for $PM_{2.5}$ and NOx. **KPI 6.2:** % of public buses and municipal service vehicles utilizing zero-emission propulsion. **KPI 6.3:** Low-Emission Zone (LEZ) implementation and targeted highly polluting vehicle drop.
7. Efficient	To maximize spatial and energetic productivity per unit of public transit infrastructure.	**KPI 7.1:** Number of passengers transported per hour per meter of lane width across different modes. **KPI 7.2:** Megajoules (MJ) consumed per passenger-kilometer traveled. **KPI 7.3:** Average peak-hour commercial operating speed of surface buses.
8. Effective	To design responsive, seamless multimodal connections that serve real human daily trajectories.	**KPI 8.1:** % of citizens able to access basic daily services within a 15 min walk or bike ride from home. **KPI 8.2:** % of mobility operators natively embedded into a single ticketing and digital routing interface. **KPI 8.3:** Average transfer and waiting time experienced by passengers at key urban transport hubs.
9. Committed	To align municipal transport funding and legislation with binding international climate and sustainability treaties.	**KPI 9.1:** Adherence tracking to legally binding global climate goals (e.g., EU "Fit for 55"). **KPI 9.2:** % of municipal capital expenditures for public works directly tied to SDG Target 11.2. **KPI 9.3:** Frequency and independent legal audit or local mobility reviews.

Table 1. *Cont.*

Decalogue Principle	Operational Policy Goal	KPI
10. Civic and social	To transform public transit corridors into safe, vital spaces for community cohesion and spontaneous human interaction.	**KPI 10.1:** Average number of citizens engaged in stationary and social activities (sitting, talking, or playing) observed in a primary public space (parks, traffic-calmed streets, plazas, etc.) per hour. **KPI 10.2:** % of pedestrian networks meeting minimum unobstructed widths >2.5 m to allow fluid conversational pass-byes. **KPI 10.3:** Average daily asset rotation rate of civic bike-sharing schemes paired with micro-mobility vandalism rates (%).

Table 2. Standardized scoring protocol and functional benchmark criteria for the 30 UMDI KPIs.

KPI	Score 0	Score 1	Score 2	Score 3	Score 4
1.1	≥10	9.9–6	5.9–3	2.9–1	<1
1.2	<10%	10–30%	31–60%	61–85%	>85%
1.3	No structural	<15%	15–50%	51–85%	>85%
2.1	<40%	40–65%	66–85%	86–98%	>98%
2.2	>12%	12–8.1%	8–5.1%	5–2.1%	≤2%
2.3	<30%	30–55%	56–75%	76–95%	>95%
3.1	<15%	15–25%	26–40%	41–55%	>55%
3.2	>10 dB	10–6 dB	5–3 dB	1–2 dB	Homogeneous low everywhere
3.3	<0.2	0.2–0.4	0.41–0.6	0.61–0.89	≥0.9
4.1	<25%	25–45%	46–65%	66–80%	>80%
4.2	Net increase/flat	<2%	2–4.9%	5–8%	>8%
4.3	Net increase	±1%	<2%	2–5%	>5%
5.1	<5%	5–15%	16–30%	31–50%	>50%
5.2	>75%	56–75%	36–55%	15–35%	<15%
5.3	<100 m	100–300 m	301–600 m	601–1000 m	>1000 m
6.1	>90 days	46–90 days	15–45 days	1–14 days	0
6.2	<5%	5–25%	26–55%	56–90%	>90%
6.3	No LEZ policy	No real drop	<15% drop	15–35% drop	>35% drop
7.1	<1500 pax	1500–3000	3001–6500	6501–10,000	>10,000
7.2	>3.5 MJ	2.5–3.5 MJ	1.5–2.4 MJ	0.6–1.4 MJ	≤0.5 MJ
7.3	<10 km/h	10–13 km/h	13.1–16 km/h	16.1–20 km/h	>20 km/h
8.1	<20%	20–45%	46–70%	71–90%	>90%
8.2	No integration	Only info; integrated separate apps	Single app for routes	App + ticket unified; partial operators	Single pay across 100% modes
8.3	>15 min	10.1–15 min	6.1–10 min	3–6 min	<3 min

Table 2. *Cont.*

KPI	Score 0	Score 1	Score 2	Score 3	Score 4
9.1	Unaligned—no targets	Targets set but no binding tracking	Mild adherence; missing milestones	Strictly on track for carbon targets	Targets reached early or net-negative
9.2	<10%	10–25%	26–45%	46–65%	>65%
9.3	No auditing	Internal reports every >4 years	Internal biannual reporting	Independent biannual audit	Certified open data annual audit
10.1	<5 people	5–10 people	11–30 people	31–60 people	>60 people
10.2	<30%	30–55%	56–75%	76–95%	>95%
10.3	>25%	15–25%	6–14%	2–5%	<2%

2.3. The Classification of Cities Based on the UMDI

The framework operationalizes the 30 KPIs presented in the assessment matrix by mapping them onto a standardized 5-point Likert maturity scale. Critical or non-compliant definition corresponds to a score of 0, which describes a complete absence of structural policy action, and regressive or harmful empirical trends (e.g., rising traffic fatalities or uncontrolled growth of private vehicle infrastructure). Low or initial definition is scored 1, describing the existence of strategic intentions primarily on planning documents, whose execution, however, is localized, timid, or purely reactive. A score of 2 (defined as moderate or progressing) describes structural interventions which are actively deployed and yield measurable results, but remain restricted to specific central districts or socioeconomic corridors. A high or advanced definition is scored 3 and describes widespread compliance with international sustainability standards, demonstrating a systemic and city-wide modal shift. Finally, excellent or benchmark/ideal corresponds to a score of 4, for those municipalities that reach the contemporary frontier of urban planning practice (e.g., achievement of absolute Vision Zero goals or complete zero-emission transition).

To transform the proposed decalogue from a conceptual and philosophical manifesto into a practical tool for political diagnosis, this paper proposes a standardized quantitative evaluation framework that normalizes various urban indicators, enabling empirical comparative analyses between different global cities. To ensure a transparent, scalable, and reproducible comparative index, an unweighted linear aggregation of the aforementioned indicators is proposed. This strategy is based on the premise that the ten dimensions of the decalogue have equal structural importance in defining a truly sustainable and transformative urban environment aligned with adaptation and resilience to climate change and all that this entails for the benefit of health and coexistence in cities.

Each of the ten principles (i) contains three distinct KPIs, yielding a maximum potential score of 12 points per principle, and an absolute raw maximum of 120 points across the entire matrix. The raw score is normalized into the Urban Mobility Decalogue Index (UMDI), expressed as a percentage on a base-100 scale, using the following formula:

$$UMDI = 100 \cdot \left[\frac{\sum_{i=1}^{30} KPI_i}{120} \right] \quad (1)$$

where KPI_i represents the individual normalized score (from 0 to 4; see Table 2) achieved by the city on the *i-th* indicator.

Once the UMDI is calculated, cities can be classified into four distinct categories or labels based on their final score. This taxonomy provides a mechanism for comparing cities in fitting the Urban Mobility Decalogue. Table 3 shows the classification and corresponding label according to the UMDI value.

Table 3. Urban performance labels and taxonomy based on the cumulative UMDI.

UMDI Score Range	Label/Color	Structural State of Urban Mobility	Main Characteristics
85–100	A/Green	Global paradigm of sustainable, equitable, and democratic urban space. Leader city.	Human-centric urban grid; full public transit modal hegemony; zero-emission mobility; infrastructure framed as a fundamental social right.
65–84	B/Blue	Active implementation of progressive policies with visible systemic shifts, yet bound by legacy challenges. Transition city.	Strong internal micro-mobility and pedestrianization networks; mature transit frameworks; structural friction points persisting at metropolitan or regional boundaries.
45–64	C/Orange	Urban ecosystems historically and physically engineered around private automobile dependency, exhibiting early, fragmented reforms. Car-centric city.	Isolated pedestrian corridors; public transit perceived as a secondary alternative for captive users; peripheral areas systematically detached from sustainable infrastructure networks.
<45	D/Red	Critical structural state characterized by systemic environmental degradation, spatial segregation, and high societal costs. Auto-dependent city.	Complete absence of active travel networks; heavy congestion and high localized pollution levels; extreme spatial and economic inequality regarding accessibility.

3. Results

To illustrate how the scoring methodology and the UMDI work in practice, they were applied to three cities with different urban planning models: Copenhagen, Barcelona, and Houston. The data sources for scoring each of the 30 KPIs that make up the UDMI equation for the three cities selected as application examples were derived from open-access municipal statistics, federally audited transportation datasets, and peer-reviewed urban monitoring tools. The primary data streams used for each urban profile were operationalized through the following official documents and active institutional databases. In the case of Barcelona, the modal distribution and traffic speed were derived from the Barcelona Sustainable Urban Mobility Plan (PMUS 2024–2026) issued by the Barcelona City Council (https://www.barcelona.cat/mobilitat/en/about-us/urban-mobility-plan, accessed on 26 October 2026), the Barcelona Public Health Agency (https://www.aspb.cat/, accessed on 26 October 2026), and the Institut d'Estudis Regionals i Metropolitans de Barcelona (IERMB), currently integrated into the research framework of the Institut Metropoli (https://www.institutmetropoli.cat/, accessed on 26 October 2026). In the case of Copenhagen, the data used were extracted from the biennial Copenhagen Bicycle Account (Københavns Cykelregnskab) published by the City of Copenhagen (Københavns Kommune) (https://www.kk.dk/, accessed on 26 October 2026), the open-access historical scoring databases of the global urban design audit framework, the *Copenhagenize* Index (https://copenhagenizeindex.eu/, accessed on 26 October 2026), and from reports by the Movia Transit Authority and the monitoring of the CPH Climate Plan frameworks for carbon-neutral transit targets (https://www.moviatrafik.dk/, accessed on 26 October 2026). Finally, for the city of Houston, data were drawn from the federally audited spatial series of the United States Census Bureau through the American Community Survey (https://data.census.gov/, accessed on 26 October 2026), from the regional databases of the Texas Department of Transportation (https://www.txdot.gov/, accessed on 26 Octo-

ber 2026), and from municipal policy reports provided by the Kinder Institute for Urban Research at Rice University (https://kinder.rice.edu/, accessed on 26 October 2026). A summarize of these data can be found in the Supplementary Materials.

Figure 1 (upper panel) shows the total value of each of the 10 KPIs based on the open data mentioned above of Copenhagen, Barcelona and Houston. Each KPI ranges from a minimum value of 0 to a maximum of 12, corresponding to each of the three indicators that make up the KPI with the highest value, 4. Figure 1 (lower panel) shows the values of each of the three sub-indicators that comprise each KPI.

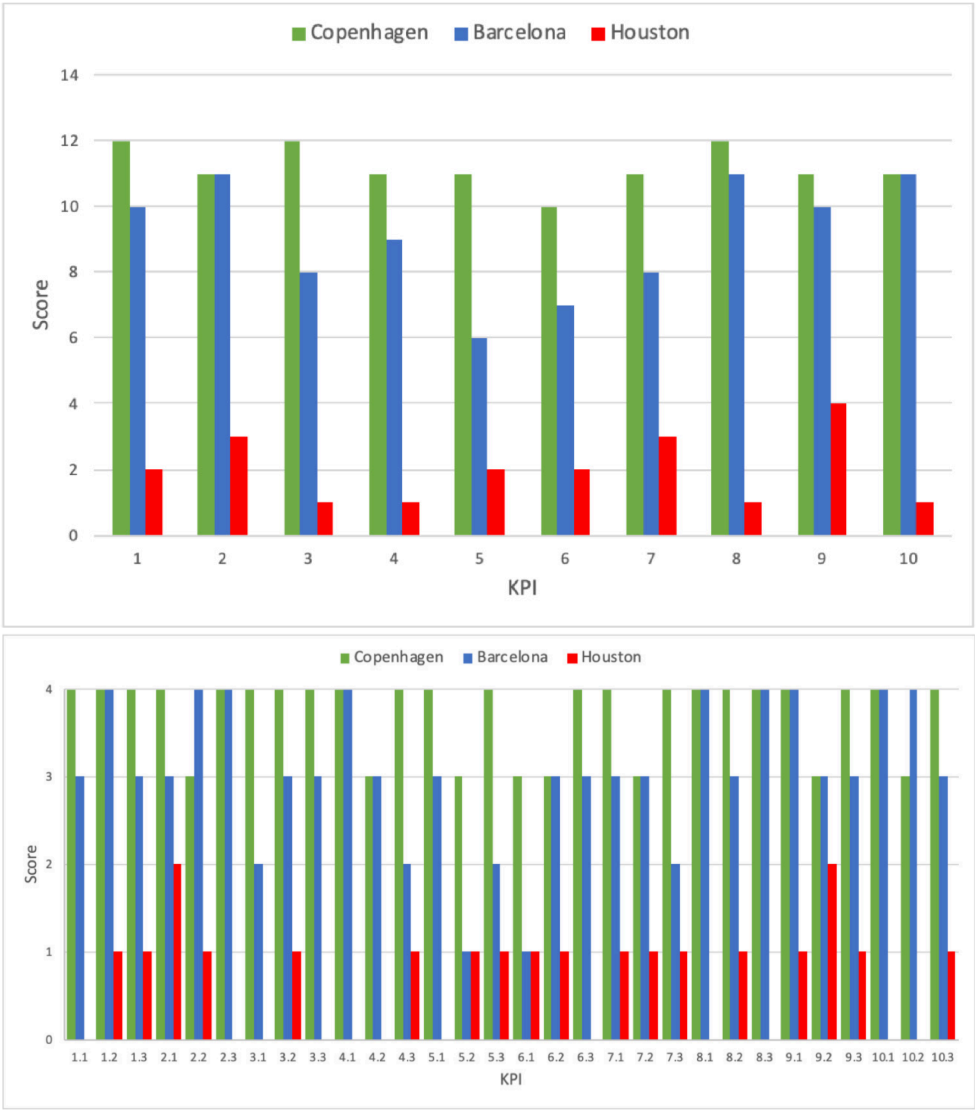

Figure 1. (**Upper panel**): Scores for each of the 10 Key Performance Indicators (KPIs) for Copenhagen, Barcelona, and Houston, calculated from the open data sources described above. Each KPI is scored on a scale from 0 to 12, representing the sum of its three underlying sub-indicators (each rated up to 4 points). (**Lower panel**): Detailed values for each of the three sub-indicators composing each KPI across the three sample cities.

From these values, the Urban Mobility Decalogue Index (UMDI) value was calculated using Equation (1). Copenhagen reached a score of 93.3, Barcelona 75.8 and Houston 17.5.

4. Discussion

Using the UMDI, urban researchers, policymakers and urban planners can move beyond traditional, reductionist classifications that solely measure traffic wait times or gross infrastructure expenditures, and work toward a comprehensive city objective that includes various aspects related to the democratization of public space, health, social cohesion, and the decarbonization of cities. The UMDI offers a holistic and balanced diagnostic tool that assesses the democratic, health, spatial, and ecological performance of modern metropolitan transport. The application of the Urban Mobility Decalogue Index (UMDI) across contrasting urban typologies (ranging from highly dispersed automobile-dependent models to compact, multimodal metropolitan fabrics) reveals that sustainable transit is not a localized engineering challenge but an ecosystemic property of urban form, political will, and spatial justice. A synthesis reveals how the ten principles of the decalogue interact between them, exposes the systemic frictions within modern city planning, and outlines the structural pathways required to transition away from car-centric path dependencies. The empirical performance profiles demonstrate that social indicators cannot be separated from environmental ones. *Safe Mobility* (point 1 in the catalog) prioritizes human life and integrity, acting as the absolute gateway to the rest of the ecosystem. In highly automobile-dependent contexts, when a city fails to provide a physically secure environment for vulnerable road users, active transportation modes collapse entirely. Safety is the baseline catalyst for *Healthy Mobility* (5 in the decalogue); without a defensive, traffic-calmed network, policies promoting walking and cycling remain fundamentally ineffective.

Concurrently, *Equitable Mobility* guarantees universal and just access to the city and *Just Mobility* the right to move free from inequalities and impacts. These points redefine infrastructure as a democratic asset. In compact, well-integrated urban fabrics, high equity scores stem from heavily subsidized, integrated pricing structures that connect low-income peripheral populations to core economic centers. Conversely, when space allocation heavily favors the private automobile, a profound spatial injustice occurs: public land is privatized for vehicle storage and movement, while negative externalities (noise, localized pollution, and heat island effects) disproportionately impact marginalized neighborhoods situated adjacent to high-speed arterial corridors.

A core finding of this framework is the necessary decoupling of technological fixes from structural spatial reforms. Many municipal frameworks conflate electric vehicle (EV) adoption with genuine sustainability. However, evaluating cities through the lens of point 6 in the decalogue, *Clean Mobility*, toward emission-free cities, and point 4, *Sustainable Mobility*, balancing social, economic, and environmental needs, exposes this fallacy.

Replacing an internal combustion engine with an electric powertrain mitigates tailpipe emissions, but it fails to address tire-wear particulate matter ($PM_{2.5}$), spatial inefficiency, congestion, or traffic safety. This structural shift requires legal and financial architecture tied to point 9, *Committed Mobility*, which should be aligned with international agreements and environmental goals. Pioneering climate-aligned municipalities leverage binding supranational climate targets (e.g., net-zero milestones) as institutional leverage. This alignment ensures that long-term infrastructure funding remains insulated from short-term local political cycles, embedding sustainability directly into the municipal capital expenditure logic.

To achieve high scores in *Efficient Mobility* (point 7), which aims to optimize space, time, and energy, urban spaces must maximize spatial productivity. Traditional car-centric metrics, such as vehicular Level of Service (LOS), prioritize the velocity of multi-ton private objects over human throughput. By pivoting to an efficiency index based on passenger capacity per hour per meter of lane width, mass public transit and cycling emerge as the only viable configurations for high-density environments. This spatial optimization feeds into

Effective Mobility (point 8), optimizing transit to achieve urban goals, which operationalizes the spatial layout of the city through structural policies like the 15-Minute City. Compact, high-density urban typologies natively support this principle. When basic human necessities are decentralized within a short radius, travel demand is fundamentally avoided rather than merely managed. The implementation of mature Mobility-as-a-Service (MaaS) platforms further optimizes the existing network capacity, removing the psychological barriers of multi-operator transfers.

Finally, the mechanical, environmental, and spatial optimization metrics serve a higher societal purpose, captured by *Civic and Social Mobility*, which fosters urban cohesion and interaction. Streets make up the vast majority of all public space in a modern city. When transportation policy treats streets strictly as throughput channels for commuter traffic, it eviscerates the social fabric of the community.

The success of dedicated bicycle highways and localized superblock or low-traffic neighborhood interventions provides empirical proof of modern public space theories: when infrastructure actively filters out vehicular dominance and guarantees wide, unobstructed sidewalks ($\geq$2.5 m), it triggers an immediate increase in stationary social activities, children playing, elderly interaction, and localized commerce. Transport networks cease to be dead, transient corridors; they transform back into dynamic platforms for community cohesion and civic democracy.

The quantitative architecture of the Urban Mobility Decalogue Index (UMDI) provides an innovative, scalable diagnostic tool for contemporary urban planning. By evaluating the structural performance of cities through a comprehensive matrix of 30 Key Performance Indicators (KPIs), this framework shifts the benchmark of metropolitan success away from vehicle throughput toward spatial justice and ecological survival.

A frequent limitation of academic urban indices is their reliance on hyper-specific, localized variables that are unavailable in data-scarce environments. The 30 KPIs proposed in this framework deliberately resolve this bottleneck by utilizing metrics that are highly standardized, publicly accessible, and readily available across virtually all mid-to-large global municipalities. The indicators leverage data pipelines that cities are already legally or structurally mandated to collect, such as traffic fatalities per capita (KPI 1.1) and demographic modal splits (KPI 4.1), which are universally tracked by public health authorities, civil registries, and national censuses, as well as environmental and operational records. The air quality metrics (KPI 6.1), local speed regulations (KPI 1.2), and public transit fleet data (KPI 2.1, KPI 6.2) are consistently monitored by municipal transit authorities and environmental protection agencies to comply with international or national regulations. For less mature digital ecosystems, proxy variables or open-access satellite data (such as Copernicus or open GIS repositories) can easily determine proximity matrices (KPI 2.3 and KPI 8.1) and sidewalk networks (KPI 10.2), eliminating the need for expensive, specialized field studies. Consequently, this matrix lowers the barrier to entry for comparative metropolitan research, allowing any city globally to be benchmarked without requiring prohibitive resource allocations for data acquisition.

The mathematical formulation of the UMDI plays a critical role in preserving the integrity and transparency of the diagnostic process. Evaluated as a linear additive sum normalized to a 100-point scale, the index assigns equal mathematical weight to each of the ten core dimensions. Adopting an equal weighting architecture is scientifically grounded in composite indicator methodology when no objective theoretical basis exists to prioritize one sustainability dimension over another, thereby preventing arbitrary value judgments and sample-dependent bias [70–72]. Furthermore, this unweighted structure acts as an institutional safeguard against greenwashing, ensuring that high performance in

operational domains cannot be strategically manipulated to overshadow critical social or environmental deficits.

In technocratic planning, municipal administrations frequently attempt to mask systemic social or spatial failures by over-indexing on highly visible technological upgrades. For example, a city might achieve a perfect score in public transit fleet electrification (KPI 6.2). However, under the UMDI formula, this isolated success cannot compensate for critical deficiencies in pedestrian safety (KPI 1.1), public space equity (KPI 3.1), or transit affordability (KPI 2.2).

Linear aggregation ensures that a high final index score can only be achieved through systemic, cross-departmental excellence, maintaining a clear and transparent overview of a city's genuine progress.

The stratification of cities into four performance categories (Classes A through D) serves as an actionable framework for political accountability and long-term capital allocation. Rather than offering a simple hierarchy, these categories define specific evolutionary phases of municipal governance, providing clear utility for different urban actors. The four performance classes translate complex urban planning telemetry into clear political accountability. Mayors and city councils can utilize the broad categories to establish legally binding, cross-departmental targets, such as passing a legislative mandate to transition a municipality from a *Class C: Car-Centric Legacy* status to a *Class B: Transitioning* status within a specific budgetary cycle. Because the metrics are tied to internationally recognized benchmarks (e.g., WHO guidelines), politicians can leverage their city's classification to apply for international green bonds, climate resilience funding, and sovereign sustainable development loans.

While the comparative evaluation of contrasting urban environments (such as Copenhagen, Barcelona, and Houston) offers valuable illustrative insights, the application of a standardized index like the UMDI must explicitly account for the profound heterogeneity of mobility regimes across diverse geographical and socioeconomic contexts. Recent empirical evidence underscores that modal structures vary significantly across cities worldwide, reflecting distinct cultural, economic, and institutional trajectories that cannot be reduced to a single developmental path [2]. Furthermore, fundamental traffic dynamics and transport efficiency are intrinsically bound to urban scale, density, and spatial morphology, which directly govern congestion behaviors and network performance [3]. Consequently, the transferability of the UMDI requires nuanced interpretation: rather than serving as a rigid, one-size-fits-all ranking tool, the index should be operationalized as a flexible diagnostic framework. By contextualizing performance thresholds against local morphological constraints and baseline socioeconomic capacities, urban planners can utilize the UMDI to identify tailored intervention pathways that respect unique local spatial realities while still driving progress toward global urban sustainability goals.

The UMDI performance labels provide a shared language for municipal authorities, grassroots advocacy groups, and real estate developers. By standardizing expectations and charting clear pathways for structural change, the framework helps align urban expansion with the core values of public health, democratic public space, and climate resilience.

In closing this discussion, while the UMDI provides a robust and scalable benchmarking framework, certain operational limitations must be acknowledged. The reliance on open-access data may introduce coverage biases in regions with lower data availability, while applying the framework to small- and medium-sized cities might require recalibrating specific KPIs to account for different spatial scales and administrative capacities. Nevertheless, the index stands as a highly transferable diagnostic tool that offers valuable guidance for urban policy and the transition toward sustainable mobility.

5. Conclusions

An Urban Mobility Decalogue was proposed. Each of the points of the decalogue was demonstrated under a scientific vision, which was transformed into an Urban Mobility Decalogue Index (UMDI) as a rigorous, replicable diagnostic framework that shifts metropolitan benchmarking away from vehicle throughput toward spatial justice, public health, and climate resilience. By implementing this 30-indicator matrix across three cross-sectional global archetypes, the index empirically exposed divergent urban trajectories and provided a precise mathematical baseline for sustainable transformation. The UMDI was applied to three cities as a sample: Copenhagen, Barcelona and Houston. Copenhagen achieved a Lighthouse City designation (Class A; UMDI: 93.3%, 112 out of 120 points), demonstrating that decades of sustained political commitment, dense active travel grids, and comprehensive traffic calming can optimize a multimodal urban ecosystem. Barcelona emerged as a Transitioning City (Class B; UMDI: 75.8%, 91 out of 120 points), showcasing how compact Mediterranean urban fabrics and innovative tactical interventions like the *Superilles* drive massive sustainable modal splits, even while the city remains constrained by regional air quality boundaries and acoustic friction points. Conversely, Houston was categorized as an Auto-Dependent City (Class D; UMDI: 17.5%, 21 out of 120 points), exposing how deeply entrenched suburban sprawl creates systemic, structural failures in traffic safety, spatial proximity, and civic vitality that cannot be remedied by superficial, isolated upgrades. These empirical results yield critical insights for contemporary urban governance, proving that genuine sustainability requires aggressive structural rights-of-way reallocations rather than mere technological fixes. As Houston's critical scores illustrate, superficial policies like private electric vehicle adoption or transit fleet electrification are fundamentally incapable of fixing an urban geometry that structurally generates massive Vehicle Kilometers Traveled (VKT) and leaves vulnerable road users entirely unprotected.

Furthermore, the linear, unweighted architecture of the UMDI formula ensures that all ten core dimensions hold equal mathematical value, serving as a vital institutional safeguard against municipal greenwashing; it prevents administrations from masking severe social or spatial inequalities behind isolated technological milestones, forcing an honest, cross-departmental assessment of urban health. Because the selected KPIs rely on highly standardized, open-access metrics already tracked by municipal authorities worldwide, the UMDI guarantees a low-barrier replication process across diverse geopolitical contexts, while its native compatibility with Geographic Information Systems (GIS) allows planners to translate abstract numerical scores into dynamic "Spatial Justice Heatmaps" that visually pair infrastructure deficits with localized socioeconomic vulnerabilities. Ultimately, the UMDI performance classes establish a transparent, shared vocabulary that bridges the gap between policymakers, transport engineers, and grassroots advocacy groups. For elected officials, the index offers clear political accountability and a data-driven pipeline to unlock international green financing, while for urban planners, it delivers the empirical leverage required to dismantle entrenched, path-dependent car-centric zoning laws. As global metropolises confront the escalating, interconnected crises of climate disruption, economic segregation, and public health declines, the UMDI serves as a vital diagnostic compass to reclaim streets not as dead, transient corridors for multi-ton machinery but as the fundamental, vibrant platforms for community cohesion, civic democracy, and human life.

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